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MEMOIRS OF THE GEOLOGICAL SURVEY

OF

ENGLAND AND WALES.

THE

TRIASSIC AND PERMIAN ROCKS

OF THE

MIDLAND COUNTIES OF ENGLAND.

BY

EDWARD HULL, M.A., F.R.S., F.G.S.

DISTRICT SURVEYOR OF THE GEOLOGICAL SURVEY OF SCOTLAND.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HER MAJESTY'S TREASURY.

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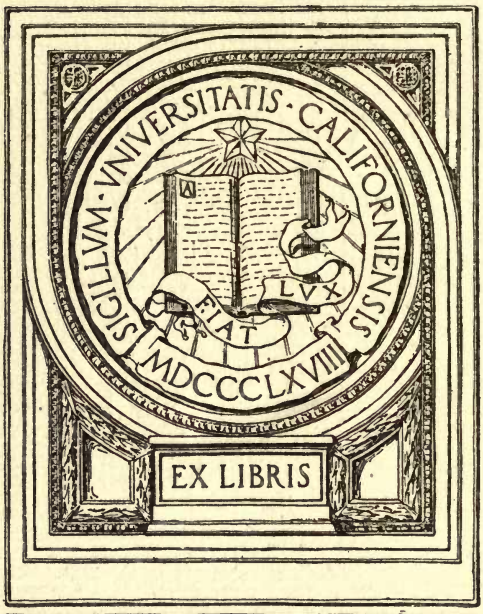

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THE PECKFORTON HILLS, CHESHIRE.—From the base of Bickerton Hill, looking northward; terraced escarpments formed of Lower Keuper Sandstone and calcareous conglomerate resting on the upper beds of the Bunter Sandstone, which form the slopes descending into the valley.

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NOTICE.

THE following able memoir on "the Triassic and Permian "rocks of the Midland Counties of England" is the result of a great amount of skilful labour.

The author, Mr. Hull, has the merit of having propounded a detailed sub-division of the Bunter Sandstone into three parts, which have been laid down in our maps by himself and the other officers of the Survey in the region in question.

The important subjects of the supply of water, and of the dimensions of the Permian and New Red Sandstone strata overlying the Coal-measures, are, as a whole, brought out clearly to public notice.

RODERICK I. MURCHISON,
Director-General.

June 18, 1869.

PREFACE.

THE area described in the following memoir has been mapped by degrees during the progress of the survey chiefly by Mr. Hull, and partly by Mr. Howell, Mr. Aveline, and myself. I have inspected the whole of it, and can vouch for its general accuracy. The south of England has not been included in the description, most of the persons who mapped the New Red strata in that region being now dead, and the detailed divisions of these strata, as now understood, not having been ascertained when that area was mapped. The equivalent strata in the north of England will be described as the survey progresses in that direction.

ANDREW RAMSAY,
Director for England and Wales.

June 19, 1869.

325139

LIST OF MEMOIRS PUBLISHED BY THE GEOLOGICAL SURVEY REFERRING TO THOSE PARTS OF ENGLAND DESCRIBED IN THE PRESENT MEMOIR.

"The Geology of the Malvern Hills, &c." By Professor J. Phillips, LL.D., F.R.S.

"The Geology of the South Staffordshire Coal-field." 2nd edit. By Professor J. B. Jukes, M.A., F.R.S.

"The Geology of the Warwickshire Coal-field." By H. H. Howell, F.G.S.

"The Geology of the Leicestershire Coal-field." By E. Hull, M.A., F.R.S.

"The Geology of the Country around Prescot," Lancashire. 2nd edit. By E. Hull.

"The Geology of Part of Leicestershire." By W. Talbot Aveline, F.G.S.

"The Geology of the Country around Wigan." By E. Hull.

"The Geology of the Country around Altrincham," Cheshire. By E. Hull.

"The Geology of Parts of Notts and Derbyshire." By W. T. Aveline.

"The Geology of the Country around Nottingham." By W. T. Aveline.

"The Geology of Parts of Notts, Yorkshire, and Derbyshire." By W. T. Aveline.

"The Geology of the Country around Bolton-le-Moors." By E. Hull.

"The Geology of the Country around Oldham and Manchester." By E. Hull.

"The Geology of the Country around Stockport, Macclesfield, Congleton, and Leek." By E. Hull and A. H. Green, M.A., F.G.S.

Besides the above Memoirs there are several "Explanations of Horizontal Sections of the Geological Survey," by Professor Ramsay, Professor Jukes, and Messrs. W. T. Aveline, H. H. Howell, E. Hull, and A. H. Green.

LIST OF MAPS OF THE GEOLOGICAL SURVEY OF ENGLAND AND WALES TO WHICH THIS MEMOIR REFERS.

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35.	72.	Including parts of the counties of GLOUCESTER, HEREFORD, WORCESTER, WARWICK, LEICESTER, STAFFORD, SALOP, DENBIGH, FLINT, CHESHIRE, DERBY, NOTTS, YORK, and LANCASTER.
43. N.E. and S.E.	73.	
44. N.W. and S.W.	74. N.E. and S.E.	
54. N.W., S.W., and N.E.	79. N.E. and S.E.	
55.	80.	
60. N.E.	81. N.W. and S.W.	
61.	82. N.E. and S.E.	
62.	88. S.W.	
63. N.W. and S.W.	89. N.W., S.W., and S.E.	
71. N.W., S.W., and N.E.	90. N.E. and S.E.	

For the Horizontal and Vertical Sections referred to in this Memoir, *see* the published Catalogue of the publications of the Geological Survey of the United Kingdom.

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THE

TRIASSIC AND PERMIAN ROCKS

OF THE

MIDLAND COUNTIES OF ENGLAND.

CHAPTER I.

Introduction.

The Triassic and Lower Permian Formations of the central and north-western counties seem destined to occupy a position of high economic importance in reference to the mineral resources of this country; and the completion of a detailed examination of these formations by the officers of the Government Geological Survey over the counties of Worcester, Leicester, Salop, Stafford, Derby, Notts, Cheshire, and South Lancaster, seems a fitting occasion for the publication of the information that has been collected by them during the mapping of these counties, especially as it may help to throw some light on the question regarding the depths at which coal-measures may lie beneath the Permian and Triassic formations.

The history of research into the Triassic rocks of England may be considered to date from the publication of Mr. William Smith's Geological Map of England in 1815, followed shortly after by that of Mr. Greenough, in both of which the "red ground" lying at the base of the Lias and separating it from the Carboniferous rocks is clearly indicated; from which circumstance the Triassic and Permian formations were classed by the earlier geologists under the term "supermedial."*

In 1819 and subsequent years, the Rev. Dr. Buckland explored and described parts of the central counties containing Triassic and Permian beds, which he has described in the Transactions of the Geological Society of London. In his memoir "On the Quartz-rock of the Lickey, "in Worcestershire, and the Strata immediately surrounding it," Dr. Buckland traces the range of the conglomerates and brecciated beds of the Lower Lickey under the title of "New Red Sandstone;" though, as we now are aware, including also strata of Permian age—and refers, though evidently with some diffidence—the quartzite conglomerates of the Bunter to the Lickey quartz-rock as their source of origin.†

But besides the fact that the upper beds of the group consisted of marls, and that the sandstones prevailed in the lower, little was known of the order of superposition of the beds, or the relations subsisting between the Trias and Permian formations in the central counties. This is the view taken by Conybeare and Philips in their work on the

* Ure's *New System of Geology* (1829). A copy of William Smith's large map may be seen in the Apartments of the Geological Society, Somerset House.

† Geol. Trans., 1st Series, vol. v. (1819). The author merely states that those pebbles "agree in substance with the quartz-rock of the Lickey."

Geology of England and Wales, published in 1822; and even in publications of later date these rocks are represented as little more than the mere washings of the older formations swept down the mountain sides into the deeper parts of the sea bed. Thus Dr. Ure in 1829, in describing the relative positions of the Carboniferous and other older formations with reference to the more recent "red rocks" of the plains, dismisses the subject in the following somewhat contemptuous terms: "The agitation of the waters would thus seem to have washed that "*pulverulent deposit* down the sides of the elevated rocks of Carboni- "ferous limestone, Old Red Sandstone, transition slate and greenstone, "strewing it over the hollows."* It would, of course, be unjust to compare some of the opinions of geologists of a past generation with the standard of the present day, and my only object in making the above quotation is to show the state of our knowledge with reference to these infra-Liassic rocks at successive periods.

In 1826 Professor Sedgwick was enabled to identify the sandstones and conglomerates overlying the magnesian limestone of the North of England as the equivalent of the Bunter Sandstone of Germany, and the variegated marls surmounting them as represented by the Keuper series of the same country,† and about the same period (1837) Sir R. Murchison and the late Mr. Strickland arrived at the same conclusions regarding the contemporaneous beds of the centre and west of England;‡ these identifications mark an era in the progress of discovery in reference to the Triassic and Permian formations of this country.

The amount of our knowledge regarding the strata between the Liassic and Carboniferous formations down to the year 1830 is clearly indicated in the pages of Sir H. De la Beche's *Geological Manual*, wherein the following correct series is given: 1. Variegated Marls; 2. Muschelkalt (absent in England); 3. Red and Variegated Sandstone; 4. Zechstein;§ 5. Todtliegendes. Very detailed descriptions of these formations are also published in the "Silurian System" throughout Gloucester, Worcester, Warwick, and Shropshire; but by all these authors, and down to the time when the officers of the Geological Survey commenced their investigations in the central counties, the Lower Permian beds of Warwickshire were grouped with the Triassic series. This was a very natural error, seeing that the Bunter Sandstone is absent in East Warwickshire, and was apparently represented by the red sandstones and marls of the Rothe-todte-liegende. The true base of the Keuper series was also unrecognized, for the "waterstones" which were classed by Mr. Ormerod in 1842 with that member of the Trias included only those thin laminated sandstones and marls, which form the upper portion of the Lower Keuper Sandstone; and as regarded the Bunter Sandstone itself, it was only looked upon as a heterogenous accumulation of sandstones and conglomerates without order or arrangement, in fact as a local "drift"; a term which has a less vague signification now than it had when applied a few years back to the Bunter Sandstone.

Notwithstanding that a key to the true classification of the Trias and Permian beds of the central counties was wanting for several years, many valuable observations regarding the extension and palæ-

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* Ure's *New System of Geology* (1829), p. 192.

† "On the Geological Relations of the Magnesian Limestone and the lower por- "tions of the New Red Sandstone series through Nottinghamshire, Derbyshire, "Yorkshire, and Durham, &c." Geological Trans., 2nd Series vol. iii.

‡ Ibid. vol. v.

§ A name given to the Permian limestone of Germany by Humboldt.

ontology of these beds were published from time to time by the following authors :—

Rev. Dr. Buckland, F.R.S.,—

"On the Occurrence of Trunks of Trees in the New Red Sandstone at Allesley, near Coventry."—Proc. Geol. Soc. London, vol. ii., p. 439. "On the Occurrence of Keuper Sandstone in the Upper Region of the New Red Sandstone in England and Wales."—Ibid. p. 453.

Sir R. I. Murchison, F.R.S.,—

"A General View of the New Red Sandstone in the Counties of Salop, Stafford, Worcester, and Gloucester."—Ibid, vol. ii., p. 115. And Mr. Strickland, "On the Upper Formations of the New Red System in Gloucestershire, Worcestershire, and Warwickshire," &c. (already cited).—Trans. Geol. Soc., 2nd Series, p. 331.

Rev. Professor Sedgwick, F.R.S.,—

"On the Magnesian Limestone and Lower Portions of the New Red Sandstone Series in their range through Nottinghamshire, Derbyshire, Yorkshire, and Durham."—Ibid. p. 37.

Mr. H. E. Strickland, F.R.S.,—

"On the Boundaries of the Red Marl and Lias in Gloucestershire and Worcestershire."—Proc. Geol. Soc., vol. ii., p. 5. "Series of Coloured Sections of the Cuttings of the Birmingham and Gloucester Railway."—Trans. Geol. Soc., 2nd Series, vol. vi., p. 545.—"On pseudomorphous Crystals of Chloride of Sodium in the Keuper Sandstone."—Journ. Geol. Soc., vol. ix., p. 5.

Mr. E. W. Binney, F.R.S.,—

"On the Relation of the New Red Sandstone to the Carboniferous Strata of Lancashire and Cheshire."—Journ. Geol. Soc., vol. ii., p. 12. In this paper the author gives the following classification of the Trias and Permian beds in descending order: 1. *Keuper.* (*a*) Red and variegated marls. (*b*) Gypseous and saliferous marls. (*c*) Waterstones (400 feet). *Bunter.* 2. Red Sandstone, 600 feet. 3. *Permian.* (*a*) Red marls with thin beds of fossiliferous limestone. (*b*) Lower Red Sandstone. "Sketch of the Geology of Manchester and its Vicinity."—Trans. Geol. Soc. Manchester, vol. i., p. 35 (1839).

Mr. J. Cunningham, F.G.S.,—

"An Account of Impressions of Raindrops at Storeton Hill, Cheshire."—Proc. Geol. Soc. London, vol. iii., p. 99.—"On some Footmarks and other Impressions in the New Red Sandstone of Storeton."—Journ. Geol. Soc., vol. ii.

Sir P. de M. G. Egerton, F.R.S.,—

"On Two Casts of a gigantic *Cheirotherium* from the New Red Sandstone of Cheshire."—Proc. Geol. Soc., vol. iii.

Mr. G. W. Ormerod, F.G.S.,—

"Outline of the Geological Features of the Salt Field of Cheshire."—Journ. Geol. Soc., vol. iv.

Professor Owen, F.R.S.,—

"On the Teeth of *Labyrinthodon* from the Sandstone of Warwick and Leamington."—Trans. Geol. Soc., vol. vi., 2nd Series, p. 503.

Mr. R. Rawlinson, F.G.S.,—

"On Foot Tracks from the New Red Sandstone of Lymm, Cheshire,"—Journ. Geol. Soc., vol. ix.

Rev. W. S. Symonds, F.G.S.,—

"Fossils from the Keuper Sandstone of Pendock."—Journ. Geol. Soc., vol. ii., p. 450.

Professor I. Phillips, F.R.S.,—

"The Geology of the Malvern Hills, &c.".—Mem. Geol. Survey, vol. ii., Part. I., p. 110.

Rev. J. Yates, F.G.S.,—

"On four Varieties of Impressions of Reptilian Footprints."—Ibid.

Mr. James Plant,—

"On the Upper Keuper at Leicester."—Ibid. vol. xii., p. 369.

Rev. P. B. Brodie, F.G.S.,—

Ibid. vol. xii., p. 374.

To some of these authors, as well as others of more recent date, I shall have occasion again to refer when treating of special districts; but I may here observe, that after studying the elaborate descriptions of the tracts surveyed by these pioneers of our science, I cannot too highly express my admiration at the amount of voluntary labour they indicate, and the masterly manner in which the subject has been handled.

More recently several discoveries of considerable interest have been made in the Permian and Triassic rocks of Central England, calculated, as is generally the case with regard to geological investigations, to modify our previous views. The reptilian remains in the Warwick Museum consisting of a cranium, discovered and described by Dr. Lloyd under the name of *Labyrinthodon Bucklandi* (Reports of the British Association for 1849, p. 56), and extracted from sandstones supposed at that time to be of Triassic (Bunter) age, have been again brought under the notice of Professor Huxley who has pointed out the generic peculiarities which distinguish it from all other previously described labyrinthodonts, and has placed it in a genus of its own, under the name *Dasyceps Bucklandi*. Professor Ramsay and Mr. Howell of the Geological Survey simultaneously showed on stratigraphical grounds, that the beds from which this specimen was extracted are of Permian age.*

Professor Ramsay has also drawn attention to the evidences of glacial conditions during the early Permian era in England, exhibited by the breccias of that formation, and has endeavoured to prove the existence of a region of high mountains in Wales and Salop composed of Silurian rocks giving birth to glaciers and ice floes, which spread their detritus to the south and east over parts of the Midland Counties.† An hypothesis which supposes a state of climatal conditions during the early Permian period, differing so materially from that which prevailed during the Carboniferous, has naturally excited much controversy; but now that the researches of Señor Gastaldi have revealed the former existence of glaciers in the Alps during Miocene times, we must be prepared for evidence of these periodic changes in past ages, which after all may not have been very sudden, and which recent astronomical investigations tend to show are not incompatible with the physical changes which the earth has undergone in its movements through space.‡

In 1853 Mr. Richard Gibbs, the fossil collector of the Geological Survey, discovered in the Lower Keuper Sandstone at Bromsgrove, a

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* "The Geology of the Warwickshire Coal-field."—Mem. Geol. Survey, Appendix, p. 54.

† Journal of the Geological Society, vol. xi., p. 189. Trans. British Association, 1854.

‡ In referring to the speculations of Mr. Croll and others, I by no means wish to ignore the probable effects of terrestrial changes of land and sea, which I first learned from Sir C. Lyell, and which I observe he still adheres to as having been the chief causes of climatal changes.—*Principles of Geology*, edit. 1867.

remarkable fish, described by Sir Phillip Egerton under the name of *Dipteronotus cyphus.** This specimen has excited the surprise of our eminent ichthyologist, not only on account of unusual characteristics as a fish, which "while on the one hand they designate it as a new generic "form, on the other, they leave it in doubt to what family it belongs," but also from its being possessed of a homocercal tail; differing in this respect from the forms hitherto found in strata below the Lias.

In 1857 Sir P. Egerton described a new species of fish under the name of *Palæoniscus superstes* discovered by the Rev. P. B. Brodie in the Lower Keuper Sandstone of Rowington† in Warwickshire. It will be observed that this specimen differs from that previously described from Bromsgrove in possessing a heterocercal tail, as is usual with the fishes of this period. Bones and teeth of Placoid fishes resembling those of the genus *Strophodus*, have been found by Mr. Plant in the Upper Keuper Sandstone at Leicester, together with Estheria and Annelide markings.‡ It is a remarkable fact that all the traces of living creatures, whether in the form of fish remains or reptilian footprints, bones, or teeth from the Triassic beds of England have been derived from the Keuper division alone, the Bunter Sandstone having hitherto proved a trackless waste.

But of all the recent discoveries of former life in the Triassic beds, perhaps that of Professor T. Rupert Jones and Mr. W. R. Parker is the most remarkable. Hitherto, with the exception of the minute *Estheria* (*Posidonomya*) *minuta*; § and fish-remains which have been obtained from the Upper Keuper sandstones and shales of Gloucestershire, Warwickshire, and other parts of the Midland counties, no fossil remains had been detected in the Red Marl which overlies these beds till 1859, when the above named observers discovered, in the blue clays associated with the gypsum beds of Chellaston near Derby, a fine series of *Foraminifera*. These they have figured and fully described in the Journal of the Geological Society.‖ The position of the gypsum beds at Chellaston appears to be about 400 feet above the base of the Red Marl. No less than 14 genera and 29 species are enumerated, many of which pass upwards through all the succeeding formations and survive at the present day. A discovery like this holds out hopes that a formation which has yielded so much may still yield more.

Reptilian footprints have been discovered in various parts of the Midland counties, Lancashire, and Cheshire; and I now proceed to give a brief enumeration of the localities. At Tarporley in Cheshire, in beds of the Lower Keuper Sandstone, *Cheirotherium Hercules* (*Labyrinthodon*) observed by Sir P. Egerton.¶ At Storeton Hill, Flaybrick Hill, Weston Point, Daresbury, and Lymm in Cheshire, similar impressions, together with others of Rhynchosaurus and several doubtful forms, have been observed by Messrs. Cunningham and Yates,** Pro-

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* Journ. Geol. Soc., vol. x., p. 369.

† Journ. Geol. Soc. vol. xiv., p. 164.

‡ Ibid, vol. xii., p. 371.

§ The little shell formerly supposed to be a mollusc and named *Posidonomya minuta* (Goldf.) has been more recently determined by Prof. T. R. Jones to be a crustacean, belonging to the genus *Estheria* of Rüppell and Baird, from specimens obtained by the Rev. W. Symonds from the Keuper of Warwickshire.—Journ. Geol. Soc., vol. xii., p. 376.

‖ Ibid, vol. xvi., p. 452.

¶ Proc. Geol. Soc. vol. iii., p. 15. *Labyrinthodon giganteus*, Owen. Geol. Trans., 2nd Ser., vol. vi., p. 537.

** Proc. Geol. Soc., vol. iii., p. 12, and Geol. Journ., vol. ii., p. 410.

fessor Harkness,* and Dr. Black ; † and at Liverpool by Mr. A. Higginson about 30 years ago, and more recently by Mr. G. H. Morton.‡ From Grinshill, Salop, bones and footprints of *Rhyncosaurus articeps*, by Professor Owen.§ From Shrewley Common, Warwickshire, footsteps figured and described by Sir R. I. Murchison and Mr. H. E. Strickland.‖ From Guy's Cliff, Warwick, by Dr. Buckland. From Cotton End, a tooth, named by Professor Owen *Cladyodon Lloydii*, first figured by Murchison and Strickland in their memoir "On the Triassic strata of Warwickshire, &c.;"¶ besides several species of Labyrinthodon from the neighbourhood of Leamington and Warwick.** From the Cubbington near Warwick a mandible of a large Labyrinthodon discovered by Mr. Richard Gibbs, Collector of Fossils to the Geological Survey, and described by Professor Huxley.†† From this part of the country the Rev. P. B. Brodie, Mr. J. Plant, and other collectors have also obtained remains of reptiles, fishes, crustacea, annelides, and plants.

In the Appendix will be found a complete Catalogue of the fossils belonging to the Trias and Permian beds now in the Warwick Museum which has been kindly drawn up for me by the Rev. P. B. Brodie.

I now proceed to state briefly the advances which have been made in our knowledge of the physical structure of the Triassic and Permian beds of Central England since the officers of the Geological Survey commenced their investigations about 15 years ago. Up to that time the Lower Permian beds of Warwickshire and Staffordshire had been grouped with the New Red Sandstone, and of this latter formation all that was known of its component members was that they consisted of three stages—A., the Red Marls ; B., intermediate beds of white and brown sandstone, with bands of marl ; and C., brick-red sandstones and conglomerates.‡‡ Since then we have determined the boundary and distinctive characters of the Lower Permian and Triassic beds of the Central counties ; we have established a three-fold sub-division of the Bunter Sandstone ; and we have ascertained the true line of demarcation between the Bunter and Keuper divisions. We have also been able to prove that between these main divisions of the Trias there is a very positive amount of unconformity, and a break, or gap in time, represented on the continent by the Muschelkalk formation. The following are, I believe, the steps by which these several results were arrived at.

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* Brit. Assoc. Rep., 1842 and 1850.

† (Weston Point) Geol. Journ., vol. ii.

‡ "Geology of Liverpool," by Mr. G. H. Morton (1863), p. 19.

§ Camb. Phil. Trans., vol. vii., "Palæontology," 2nd edit., p. 263.

‖ Geol. Trans., 2nd series, vol. v.

¶ Ibid, plate xxviii., fig. 6. *See also* Owen's "Palæontology," 2nd Edit., p. 278.

** Described by Professor Owen under the names *L. pachygnathus*, *L. scutulatus*, *L. ventricosus*, Geol. Trans., 2nd series, vol. vi. I may add that my friend, Mr. J. Cunningham, F.G.S., of Liverpool, has in his possession what *seems* to be the cast of the foot of a huge reptile, surpassing in size any that has yet been discovered. I am assured by the owner that in its present state, owing to the effect of weathering, the cast is not so perfect as it was when first taken from the quarry at Flaybrick. An apparently new species or genus recently discovered by Mr. J. W. Kirkham from the Lower Keuper Sandstone at Daresbury Hill is figured and described by Professor Williamson, F.R.S., Journ. Geol. Soc., vol. xxiii., p. 55. Mr. Kirkham is an indefatigable worker, and amongst other objects has recently (1867) extracted from the Keuper beds of Western Point a cast of what seems to have been the flower of a plant.

†† "*Geol. of the Warwickshire Coal-field.*" Mem. Geol. Survey, Appendix, p. 56.

‡‡ I take this classification from the first edition of Mr. Jukes' "Memoir on the "South Staffordshire Coal-field" (1853), because it gives a very fair account of our knowledge up to that time. *Records of the School of Mines*, vol. i., part 2, p. 152.

During the year 1851, while engaged in mapping the "red rocks" along the southern margin of the North Staffordshire coal-field, I at first contented myself with drawing a general divisional line between the Coal-measures and the red sandstones which overlie them; but I soon began to perceive that there was a marked distinction between these red sandstones, which we now know to be of Lower Permian age, and the quartzoze conglomerates which succeeded them in ascending order.* I then commenced to trace a base line for these conglomerates, and on finding that they gradually overlapped the Lower Red Sandstone, and (east of Longton) were found eventually to rest on the Coal-measures, it became clear to me that this line was the true base of the Bunter Sandstone.† This line of demarcation I subsequently traced along the margins of the South Staffordshire and Coalbrookdale coal-fields, and my colleagues, Professor Ramsay and Mr. H. H. Howell, extended the same divisional lines into Warwickshire and around the district of the Clent and Lickey Hills; while Mr. W. T. Aveline and myself carried out the survey along the Flintshire, Denbighshire, and Shrewsbury Coal-fields, and southwards into the Bridgenorth and Enville country. This was the first, and perhaps most important, step in the process of our modern classification, and, taken in conjunction with the determination of the representative formations by Mr. E. W. Binney at Manchester several years earlier,‡ embraced nearly the whole of the area now under consideration.

The next step was the determination of the three-fold division of the Bunter Sandstone, and of the true base of the Keuper series; and how this was made may be briefly related. Towards the latter part of the year 1852 Professor Ramsay, while engaged on a tour of inspection amongst the hills at the northern side of Delamere Forest, in Cheshire, observed the repetition of similar lines of escarpments, separated by valleys, and expressed his opinion that these features were probably due to the existence of faults in connexion with denudation. In order to ascertain the truth of this view, as well as to trace out in the maps of the survey the lines of dislocation, he directed me to follow, through the

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* That the key to the separation of the Triassic and Permian rocks of Salop, Warwick, and Stafford was first discovered by myself is stated by Professor Ramsay in his introductory lecture on the opening of the School of Mines in 1852, where he says, in speaking of these formations and their relationship to the Coal-measures, "It "chanced, however, last year, that by dint of constant practice and study in the "field, my colleague, Mr. Hull, discovered a key to the separation of these rocks "from any others of the district; and the progress of the mapping of the country has "shown that ~~everywhere, except~~ in accidental cases, they (the Permian beds) rest "unconformably on the Coal-measures, and that the New Red Sandstone is uncon-"formable to both."—"Records of the School of Mines," vol. i., part 1, p. 95.

† Mr. Jukes, in reference to this subject, states, "If the survey had been confined "to the immediate neighbourhood of the South Staffordshire Coal-field it would "have been impossible to have obtained sufficient evidence for establishing a "boundary between the New Red and the Lower Red Sandstone. In North Stafford-"shire, however, I believe better sections exist, and my colleague, Mr. Hull, in "examining that district, was enabled to acquire a knowledge of the characteristic "distinctions of the two formations, which he afterwards brought to bear on the "examination of our district."—"S. Staffordshire Coal-field," 1st edit., p. 156. Mr. Jukes is under a mistake as regards two points in the above passage; first, there are not better sections in North Staffordshire than in South Staffordshire; and, second, it was not by means of the "better sections" that I was enabled to define the limits of the two formations, but for reasons stated above.

‡ "*On the Geology of Manchester, &c.*"—Trans. Geol. Soc., Manchester, vol. i., p. 35.

whole range of hills, the feature which is there produced by a hard calcareous rock surmounting banks of soft sandstone. This hard rock, sometimes becoming a conglomerate, I found to form an excellent line of demarcation, generally crowning a cliff; and by its repetition through the agency of faults producing the striking features of the Peckforton Hills and Delamere Forest (see Figs. frontispiece and page 75). The line I was tracing ultimately proved to be the true divisional boundary between the Keuper and Bunter divisions of the Trias.

While thus occupied with the rocks of the hilly district of West Cheshire, I could not but remark that, on leaving the hills and crossing the strike of the beds, there was generally to be found a second, but less prominent, ridge of hard sandstone with pebbles, and not unlike the rock which ran along the crest of the escarpment. This sandstone was found to dip towards the hills; but whether it was a lower member of the Trias, or the same as the rock on the hills, repeated by a fault, I could not for some time ascertain, owing to the absence of sections. Observing the persistency of this lower hard sandstone for several miles as far as Malpas in Cheshire, I began to feel certain that it was a lower member of the Bunter Sandstone; and on tracing it as far as Shiffnal in Shropshire the matter was set at rest on observing the fine sections laid open along the Shrewsbury and Birmingham Railway. Here, not only did I find the hard pebbly sandstone to dip under the soft red sandstone at the base of the Keuper series, but that it was itself underlaid by a second member composed of soft red sandstone, which, in turn, surmounted the red sandstones and marls of the Permian series. I was afterwards pleased to find that Mr. Williams, formerly of the Geological Survey, had correctly indicated on a MS. horizontal section the succession of the Triassic beds in this neighbourhood. There are, indeed, few spots in England where the entire sequence from the Permian beds upwards into the Keuper Marl is more clearly displayed, or can be more conveniently studied.

It became clear, therefore, that in Cheshire and Salop the Trias consisted of, first, a lower series of soft red sandstones; second, hard pebbly sandstone passing into conglomerate; third, an upper series of soft red sandstones surmounted by calcareous sandstone and conglomerate of the Keuper division, which in turn was overlaid by the Waterstones and Red Marl; and it then became a question whether these divisions were capable of being followed out over the whole of Central England. Professor Ramsay, who at once saw the importance of this question, directed Mr. Howell and myself to prosecute the inquiry, and the result has proved that these sub-divisions (with occasional modifications of mineral character) are capable of accurate delineation whenever they occur, and represent the successive stages in the history of the Trias over the whole country.

Theoretically and practically the results are briefly as follows:—By means of these sub-divisions we are enabled to interpret the causes of the physical features of the Triassic districts; we have been enabled to mark out lines of dislocation over large tracts, and to estimate the amount of displacement of the beds on either side; and we are now able, with some approach to accuracy, to estimate the thickness of the Triassic rocks in any given locality where they are not much concealed by drift deposits. With what small prospects of success any attempt might have been made to estimate the thickness of this formation over parts of Lancashire, Cheshire, Salop, and Warwickshire before the establishment of these sub-divisions it is scarcely necessary to remark; nor could we have had much hope of arriving at any definite results in the attempt

to solve this branch of the problem regarding the depth of the Carboniferous rocks.

The next question requiring solution was the true base of the Keuper series. Several English geologists had been in the habit of very properly grouping the evenly bedded brown sandstones and shales, or "passage beds," which lie at the base of the Red Marl, with the Keuper; but the underlying hard sandstones and freestones, with a base of calcareous breccia, or conglomerate, had always been associated with the Bunter Sandstone. While engaged in tracing the divisions of the series as already stated, I was gradually coming to the conclusion that the calcareous breccia was itself the true base of the Keuper series; for I could not but observe that there was no sign of a break in the sequence from this rock upwards into the passage beds of the Red Marl, while it was perfectly certain that the soft red sandstone on which it rested was a member of the Bunter series. At this point, then, *there did* appear to be a break, sometimes represented by an eroded surface; and by a process of exhaustion, there being no room, as it were, either above or below the base of the calcareous breccia, for the intervention of that period during which the Muschelkalt of Germany was in course of formation, I was lead to conclude that the calcareous breccia and the overlying freestones, often of considerable thickness, ought to be included in the Keuper, rather than in the Bunter, division of the Trias.

Professor Ramsay has since informed me that he had arrived simultaneously at a similar conclusion regarding the sandstones below the Red Marl in the neighbourhood of the Warwickshire coal-field. It is satisfactory, therefore, as corroborating these views to find that while engaged in the survey of these rocks in different districts, we had arrived at the same results upon independent grounds.

If any confirmation were required of the conclusions here arrived at it would be found in the determination of the unconformity between the Bunter and Lower Keuper Sandstones in Lancashire and Cheshire, and the evidence there is of the sandstone of the Bunter having undergone a considerable degree of erosion, or denudation, before the deposition of the upper division of the Trias. Evidences of this I shall offer in a future page; but I refer to the fact here on account of its bearing on the question of the true divisional line between the Keuper and Bunter series. Regarding the cause of the absence of the Muschelkalk in England I shall offer a few suggestions, when I come to deal with the physical geology of the Trias.

The classification of which I have now given the history has been adopted by the Geological Survey, and the several divisions will be found drawn and coloured on the published maps and sections. I here subjoin a general chronological description of the series, with their continental equivalents, from the Rhætic Beds downwards, as found in the central counties of England. In this series I have omitted all reference to the St. Cassian beds which contain so large an assemblage of organic remains, both of Palæozoic, Mesozoic, and peculiar forms in somewhat abnormal positions, because there is still some uncertainty regarding their affinities to the British series. It seems not improbable that different portions of this group may represent a continuous series of calcareous deposits, representing both the Permian, Triassic, and Rhætic beds of England, while the whole mass has been, as Professor Ramsay has suggested, completely inverted.*

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* Anniversary Address to the Geological Society of London. Journ. Geol. Soc., vol. xx. p. xlvi.

General Classification.

			Foreign Equivalents.	
TRIASSIC SERIES.	A. 1. Rhætic or Penarth Beds occurring at Copt Heath and the South-west of England.			
	A. 2. New Red Marl	Red and grey shales and marls, sometimes micaceous, with beds of rock-salt and gypsum, containing *Estheria* and *Foraminifera* (Chellaston).	Keuper - -	Marnes irisées.
	A. 3. Lower Keuper Sandstone.	Thinly laminated micaceous sandstones and marls (waterstones); passing downwards into white, brown, or reddish sandstone, with a base of calcareous conglomerate or breccia.	Letten Kohle (?)	„ „
	B. Wanting in England	- - - - -	Muschelkalk -	Calcaire conquillien.
	C. 1. Upper Mottled Sandstone.	Soft, bright-red and variegated sandstone (without pebbles) - - -	Bunter Sandstein.	Grès bigarré, or Grés des Vosges (in part).
	C. 2. Pebble Beds -	Harder reddish-brown sandstones with quartzose pebbles, passing into conglomerate; with a base of calcareous breccia - -		
	C. 3. Lower Mottled Sandstone.	Soft bright-red and variegated sandstone (without pebbles) - - -		
PERMIAN SERIES.	1. Upper Permian -	Red marls, with thin bedded fossiliferous limestones (Manchester).	Zechstein.	
	2. Lower „ -	Red and variegated sandstone (Collyhurst, Manchester) represented by -	Rothe-todte-liegende.	Grés des Vosges (in part).
		Reddish-brown and purple sandstones and marls, with calcareous conglomerates and trappoid breccia. (Central Counties) - -		

CHAPTER II.

Lower Permian Rocks.

The detailed description which the Permian series of the Central and Western counties has received at the hands of previous authors renders it unnecessary for me to do more than give a general and rapid sketch of the nature and position of these rocks over the tract of country embraced by this memoir. The name for the whole group was first suggested by Sir R. Murchison in the year 1841, and certain beds belonging to this group in Worcestershire, Shropshire, and Staffordshire, such as the Alberbury calcareous breccias, and the red rocks of South Staffordshire, overlying the Coal-measures, were described by him in the "Silurian System," 1839, under the name of the "Lower New Red Sandstone," as being representatives of the Rothe-todte-liegende of Germany; these observations have been amplified in subsequent editions of "Siluria."

In 1853 Mr. Jukes described the results of the joint researches of himself, Professor Ramsay, and the author, in South Staffordshire and western parts of Warwickshire, and this was followed by an elaborate memoir by Professor Ramsay, read before the Geological Society of London, in which he described the trappoid breccias, with their associated beds in Staffordshire, Shropshire, and Worcestershire; and, referring their formation to ice-agency, drew from thence his well-known con-

clusions regarding the existence of glaciers and icebergs in the Permian Period.*

In 1857 Mr. Howell published his memoir on the Warwickshire coal-field,† in which is described that large tract of Permian beds lying to the south and west of the Carboniferous rocks, and in which Professor Ramsay discovered the casts of *Strophalosia*, a well-known genus of Permian brachiopods.

These beds are but sparingly represented around the Leicestershire coal-field, but in my memoir on the geology of this Coal-field ‡ certain breccias at Measham are there classed with this formation. The representatives of the Permian series as they occur in North Staffordshire, Salop, and Denbighshire have also been described at intervals in the short explanatory sheets, written to accompany several horizontal geological sections levelled over these tracts, and published by the Geological Survey. The Permian series of South Lancashire has from time to time been ably described by Mr. E. W. Binney, F.R.S., in several memoirs published in the transactions of the Geological Society of London, and of the Literary and Philosophical Society of Manchester,§ and has been subsequently treated in several memoirs of the Geological Survey descriptive of the same district.‖ It will thus be seen that there are few portions of the country to which this memoir refers in which the Permian formation has not been already described in more or less detail. This will be a sufficient apology for rapid treatment in these pages of a formation which I shall deal with as introductory to the more detailed description of the Triassic series.

Two Types of Lower Permian Rocks.—The Lower Permian series of the western and central parts of England may be arranged under two distinct types of strata, of which those at Enville, in Shropshire, and the sandstone of Collyhurst, near Manchester, may be considered as representative beds. To the Salopian type may be referred the whole of the Permian rocks as they occur in Shropshire, Staffordshire, and Warwickshire ; and to the Lancashire type, the rocks of this formation as they occur at Stockport in Cheshire, in South Lancashire, and the north-west of England. At one time I was under the impression that the Enville beds were of older date than the Collyhurst sandstone, as being lithologically more closely allied to the Coal-measures, but fuller knowledge of the nature and relations of the Permian and Carboniferous rocks has led me to the conclusion that they are strictly contemporaneous, but deposited in separate hydrographical basins ; the disconnecting barrier having been produced by the upheaval of the Lower Carboniferous rocks along a tract of country crossing from east to west below the central plain of Cheshire.¶ There is evidence in these formations themselves of the formation of such a barrier, to which I shall revert in a future page. If we reject this view we are brought, I think, in face of two difficulties.

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* Geol. Journ., vol. ii., p. 185.

† "On the Geology of the Warwickshire Coal-field."—Mem. Geol. Survey, by H. H. Howell, F.G.S.

‡ "On the Geology of the Leicestershire Coal-field and the Country around Ashby-de-la-Zouch."—Mem. Geol. Survey. These beds had been described by the late Mr. Mammatt in his "Geological Facts," and had been identified as Permian by the late Rev. W. H. Coleman before the Survey entered the district.

§ Geol. Journ., vol. ii., and Mem. Lit. and Phil. Soc., Manchester, vol. xii. (1855).

‖ "Geology of Bolton-le-Moors," "Geology of Oldham and Manchester," &c.

¶ In a paper recently read before the Geological Society of London "on the "evidence of a ridge of Lower Carboniferous rocks crossing the plain of Cheshire beneath the Trias, &c.," I have entered fully into this question (1869).

First; assuming that the Enville and Manchester beds are contemporaneous, is it probable that two such totally dissimilar groups could have been found in such close proximity and in the same basin?

Secondly; assuming that the Enville beds were of earlier date than those at Collyhurst, we have to account for the absence of representative beds over each of these areas. A much more probable explanation seems to me to be that I have suggested, namely, deposition in distinct basins. In treating of these two types of Permian Strata, we shall commence with the Enville series of the Central counties, and afterwards consider the characters and distribution of the Lancashire series.

Part I.

Lower Permian Beds of Enville and the Central Counties.

Salopian Type.

Mineral Characters.—It is not very easy to convey a definite impression of the general characters of these variable strata by mere description, as they have a peculiar *facies* of their own, only to be comprehended by observation of several districts in the field. Taken as a whole, they may be described as consisting of a series of red, purple, and brownish sandstones, irregularly bedded, alternating with thick beds of red marl or clay; and with these are associated calcareous conglomerates, trappoid breccias, and earthy limestones of a concretionary nature resembling the "cornstones" of the Old Red Sandstone of Herefordshire. The same terms might be applied to describe the Triassic series; but there is a marked distinction in the fact that the marls of the Trias are confined to one definite horizon, and the sandstones to another. In the Permian beds, on the other hand, we never find those peculiar quartzose conglomerates so well developed in Staffordshire, nor do we find in the New Red Sandstone thick beds of purple marls lying between others of sandstone, as in the case of the Permian series. That the two series are physically distinct, though having a somewhat general lithological resemblance, is proved by their marked unconformity to each other.

On the other hand, the Permian beds are distinguishable from the Coal-measures by the absence of coal,* and of yellowish or grey sandstones, and blue, grey, or dark shales, which are characteristic of that formation. The two formations are also unconformably superimposed in several localities, especially along the east side of the South Staffordshire Coal-field; as very clearly established by Mr. Jukes.† The Permian beds also contain strata which are never found amongst the Carboniferous series of this district, such as the calcareous conglomerates and the subangular trappoid breccias; and we may therefore assert that this group of strata, although bearing some marks of resemblance to the Upper Coal-measures and Triassic series, is lithologically, as well as stratigraphically, distinct from both, and forms a group with an individuality all its own.

Enville and Bridgenorth Districts.—The Permian strata of this district have been very fully described by Sir R. I. Murchison in "The Silurian System," and correctly referred by him to the Lower New Red, or *Rothe-todte-liegende*, so far back as 1839; and there is probably

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* Except, perhaps, in one doubtful case mentioned by Mr. Jukes at West Bromwich. From the account of this section I should be inclined to consider the beds in which this seam occurs as Coal-measures. See South Staffordshire Memoir, 2nd edit., pp. 11, 12.

† Ibid, p. 135.

no district where so complete a succession of the Lower Permian series is presented as in the neighbourhood of Enville, south of Bridgenorth in Shropshire. I therefore adopt this as a typical district for these beds, just as it may be considered a typical district for the New Red Sandstone. Any one who wishes to study the character and relations of these two groups of strata cannot do better than visit this part of England; for here he will find them in their highest state of development, and laid open along many natural, as well as artificial, sections. The following figure, reduced from the horizontal section (No. 2, Sheet 53) of the Government Survey, will serve to show the succession of the beds in this neighbourhood. The whole series attains a thickness of about 1,500 feet.

Fig. 1.

HORIZONTAL SECTION ACROSS THE PERMIAN SERIES.—ENVILLE, SALOP.

C. Coal-measures. B 3. Lower Series of Permian beds. 2. Middle Series. × calc. conglomerate. × × breccia. 1. Upper Series. A. New Red Sandstone resting unconformably on the Permian beds.

(B 3.) The lowest beds rest upon the Upper Coal-measures of the Forest of Wyre. They consist of purple sandstones, passing into various shades of red, brown, and, in one or two instances, white; they are often calcareous, and mottled with carbonaceous spots, and are shown in quarries two miles south of Bridgenorth, in the Kidderminster road, and at Uplands. The sandstones are interstratified with red marls, and the thickness of this series is about 850 feet.

(B 2.) These are succeeded by a middle series, containing calcareous conglomerates and trappoid breccias separated by beds of sandstone and marl, thus—

(B.) Middle Series	Breccia in a marly base	60 to 120 feet.
	Sandstone and marl	40 „ 50 „
	Calcareous conglomerate	0 „ 30 „
	Sandstone and marl	30 „ 40 „
	Calcareous conglomerate	0 „ 12 „

(B 1.) The upper series consist (like the lower) of red and purple sandstones and marls, and represent the highest beds that we know of in this part of England.

Middle Series.—The calcareous conglomerates, occurring here in two beds separated by sandstones and marls, are a characteristic feature of the Lower Permian series both in this district, as well as along the margins of the South Staffordshire and Coalbrook Dale Coal-fields. I have no doubt they are on the same horizon as the Alderbury breccia hereafter to be described, their components being identical. The more rounded form of the fragments at Enville and South Staffordshire is probably to be attributed to the greater distance they have been transported from their parent rocks.

The upper bed is quarried at "The Green" on the Bridgnorth road. It is seven feet thick, resting on marl and surmounted by brown sandstone, and at Four Ashes is composed of fragments of the following rocks, as determined by Professor Ramsay:—Carboniferous limestone, pieces of chert, sandstone, quartz, quartz rock, Silurian limestone of doubtful age, greenstone, felspathic trap, banded felspathic

ash, red granite, red sandy marl, red sandstone, black slate, red jasper and hornstone. The Carboniferous limestone pebbles predominate.*

The pebbles are generally waterworn, sometimes sub-angular, and bound together by a hard calcareous sandy cement.

The conglomerates may also be viewed at Gateacre Green, Six Ashes, No Mans Heath, and Compton, at which latter place they attain a thickness of 60 or 80 feet. The section in this latter spot is the most remarkable, from the fine example of jointage which the beds present. The joints are hollow, nearly vertical, and range in a direction N. 20 E. parallel to the large fault which terminates the beds to the northward. The relationship of the system of joints to the fault is here very evident.

These conglomerates are local and inconstant both here and elsewhere, but that their presence marks a definite horizon about the centre of the Permian series there can be no doubt. They are the fragmentary representations of an old shingle beach, which once stretched at intervals over a large part of Salop and the adjoining parts of England.

The trappoid breccia presents, in the angularity and diversity of its component pebbles, a marked difference to the conglomerates underneath. It consists of an incoherent assemblage of angular, or sub-angular, fragments of felspathic trap, porphyry, red syenite, greenstone, baked or altered slate, and ashy sandstones, and a few pebbles of quartz, of various sizes up to six or eight inches in diameter in a marly base, and often presenting faint, but clear, indications of ice-action in the polishing and striation of the sides. The breccia attains its greatest thickness at Enville, forming a range of steep sided hills, with a smooth undulating surface, called the "Sheep Walks" of Enville Park, and trending in a north-west direction along the general strike of the beds, till terminated by the large fault already referred to. The thickness of the breccia is about 300 feet, but it seems to become thinner northwards. I have already referred to Professor Ramsay's view of the glacial origin of these remarkable beds.†

The calcareous conglomerates of Coton, and "The Bowells," are so fully described by Sir Roderick Murchison in "*The Silurian System*," that I cannot do better than reproduce the passage here. Their thickness at the latter place is from 20 to 30 feet. "The upper beds (*a*) contain rounded pebbles of Carboniferous limestone, some with an oolitic structure containing encrinites, corals, and terebretulæ; the lower beds (*b*), conglomerate with fewer pebbles of limestone, but others of quartz, Old Red Sandstone, &c. the whole cemented by pure white crystalized carbonate of lime. This rock passes into calcareous sandstone with pebbles of quartz and small fragments of jasper." Sections also occur at Shropshire Farm, and along the flank of the hill west of Romsley.

Upper Series.—The upper series is similar to the lower, consisting of pale brown and purple sandstones, speckled and interstratified with bright red marls. Sections in these beds may be seen at Ashforth Mill near Claverley, where they are much disturbed, being in proximity to the large boundary fault; they may also be seen at Upper Bea Bridge, Trilly Brook, and Morfe Mill. I am not aware that these beds are shown in any other locality; for in the Clent Hill district they are concealed beneath the New Red Sandstone.

Nearly the whole of the series in the Enville country dips steadily towards the north-east, and is considered to be repeated by a fault; this

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* "On the Permian Breccia."—Geol. Journ., vol. xi., p. 189.

† Ibid, 195, *et seq.*

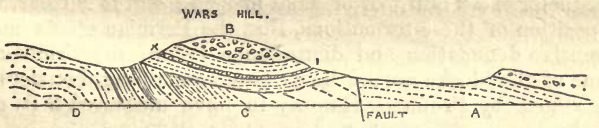
at least is the lesser of two difficulties, either of supposing the whole of the Permian series to be twice its usual thickness, or that the same series was deposited twice over in the same order. The supposition of a fault is almost placed beyond doubt by the re-occurrence of the breccia in the form of an outlier on a hill north of Romsley, and in a position above the calcareous conglomerate exactly as at Enville. The amount of displacement of the fault is about 1,000 feet.

Outliers of Permian Breccia between Enville and the Malvern Hills.—These outliers are described in detail by Professor Ramsay in the memoirs already quoted. Between the Abberley and Malvern Hills they form a series of detached masses, and, along with other more recent breccias and conglomerates of Triassic age, are described by Professor Phillips in his treatise on "The Geology of the Malvern Hills," published in the Memoirs of the Geological Survey (1848). When this work was written, the distinctive characters and relations of the Triassic and Permian strata were not recognized in this region of England, and hence the littoral accumulations of these groups of strata are in this work referred to the Triassic period only. More recent investigations of the geological surveyors have shewn that these accumulations not only belong to two unconformable sets of strata on either side of the line which marks off the Palæozoic from the Mesozoic periods, but that the brecciated gravels and conglomerates of the Trias in this district represent successive stages, and special geological horizons, belonging to that formation itself.

I now proceed to describe the strata of the Permian series, from the southern extremity of the district embraced by this memoir, northwards, availing myself largely of the details recorded by previous authors, and commencing with the outlying fragment of Wars Hill.

Fig 3.

Section across Wars Hill (after Ramsay).*



A. New Red Sandstone. B. Permian beds; breccia resting on sandstone and marl with conglomerate (×). C. Coal-measures. D. Old Red Sandstone.

Wars Hill.—This outlying patch of breccia rests unconformably on Coal-measures close to their junction with the Old Red Sandstone. The lower beds consist of sandstone and marl with a bed of calcareous conglomerate identical with that at Enville. These beds are capped by breccia of pebbles consisting of grey sandstone, grey slate, ashy sandstone, felspathic trap, and Carboniferous limestone chert. No good sections were exposed to view.

Stagbury Hill.—At this spot the breccia occurs on the west side of a fault which introduces the New Red Sandstone. The beds dip eastward towards the fault at angles of about 50°. The fragments of rock consist of felstone, felspathic ash, greenstone-porphyry with large crystals of felspar, greenstone, ribbon slate, grey and purple grits, coarse

* The descriptions here given are chiefly drawn from Professor Ramsay's Memoir, Geol. Journ., vol. xi., pp. 191–194.

conglomerate, and red micaceous sandstone, apparently from the Old Red series.

Church Hill.—Lying at a distance of several miles to the westward of the general range of the Triassic and Permian formations, we find the singular outlier of brecciated rocks of Church Hill, covering a space of less than a square mile, and resting on the southern limb of the Forest of Wyre coal-field. The true Permian character and affinities of this isolated mass were first determined by Professor Ramsay, who rightly observes that the existence of this fragment, so far to the westward, serves to show that the beds once extended many miles across the country to the west, and have suffered largely from deundation. The breccia rests unconformably on Coal-measures, and contains angular stones of indurated sandstone, purple grits, red conglomerate (masses sometimes from two to three feet in diameter), greenstone, felspathic porphyry, and ash slate, sandy limestone, and indurated black sandstone, the whole in a bright red marly base. In this locality the fragments are unusually angular and broken, and may be identified with the Cambrian and Llandeilo beds in Shropshire and Montgomeryshire to the northward.

Woodbury and Abberley Hills.—Rising to a conspicuous elevation above the Triassic plain to the eastward, and of 975 feet above the sea-level, is the ancient camp of Woodbury Hill, formed of Permian breccia resting on the truncated edges of the Upper Silurian shales and limestones, which, along this part of their range, appear to have undergone a complete *boulversement*, as we find them resting on the beds of the Old Red Sandstone. The patches here are in a position still further south than those previously described, but differ in position from them in resting on Upper Silurian rocks. The beds dip eastward towards the New Red Sandstone, against which they are terminated by a fault.

About a mile further to the north, and occupying a similar geological position, is the Permian outlier of the Abberley Hills, also formed of breccia in a marly base, and dipping towards the south under the Trias. In this case the boundary with the newer Mesozoic rocks seems to partake of the character of a "cliff," or original margin; and it is clear, from the relative position of these formations, that the Permian strata had undergone extensive denudation and disturbance before the Triassic period. Here some of the blocks are of large size, resembling boulders, one of which is stated by Professor Ramsay to have measured 2 ft. 4 ins. by 1 ft. 6 inches.

Berrow Hill.—The breccia here rests partly on Old Red Sandstone and partly in Coal-measures, passing over their highly inclined edges. The fragments consist of greenstone, trappean breccia, felstone, felspar porphyry, purple grit, and slate. This is the most southerly representative of the Permian strata to which I shall refer.

Having traced these strata to the extreme southerly limits of the tract embraced by this memoir, let us now cross to the north-east over the Triassic formations around Kidderminster and Stourport, under which these Permian beds may be considered to dip, till we arrive at the southern borders of the South Staffordshire Coal-field, where they again emerge and rise into the undulating hills of the Clent and the Lickey range.

District of the Clent and Lickey Hills.—The Permian rocks form a tract of hilly and highly picturesque country, ranging from west to east along the southern margin of the Dudley Coal-field, the highest parts of which are composed of beds of breccia. The whole of these strata have a southerly dip, and disappear beneath the New Red Sandstone towards Bromsgrove. Strips of the same formation, of varying breadth, are inter-

posed between the boundary faults of the coal-field and the New Red Sandstone, on both sides, extending as far north (with one or two intervals) as Great Barr on the east, and Essington Wood on the west.

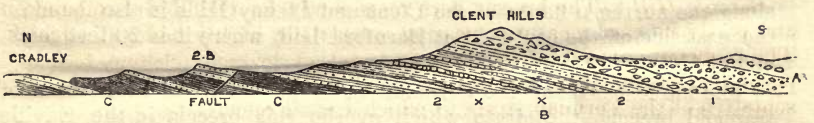
As far back as 1819 the brecciated beds of the Clent and Bromsgrove Lickey Hills were faithfully described by Dr. Buckland, who pointed out that they were truly stratified deposits, enumerating amongst the fragments of older rocks which they contained, specimens of quartz-rock, similar to that of the Lower Lickey, white quartz, black and variegated jasper, flinty and chloritic slate, many varieties of porphyry and of grey and variegated compact and granular sandstone. Professor Ramsay has since shown that these quartzite pebbles cannot have been derived from the Lower Lickey, as this Silurian ridge owes its upheaval to faults of more recent date than the Permian.*

Subsequently, however, Dr. Buckland's views appear to have been lost sight of; and the Clent Hills, owing to the abundance of fragments of trappean rocks which are to be found scattered over and around them, were considered by subsequent observers to be composed of trap rock, although no actual mass of this rock *in situ* could be observed. During the year 1851–2, however, while engaged on the survey of the formations surrounding the coal-field, I gradually came to the same conclusion as had Dr. Buckland (though not then aware of his views) regarding the stratified character of the rock and its connexion with the underlying Permian strata.† In the spring of 1852, Professor Ramsay and Mr. Jukes made a more detailed survey of the district, the results of which have been described by the former in his paper on "the "Permian breccia of Shropshire, &c.," already quoted, and by the latter, in his memoir on the South Staffordshire coal-field.

The lower beds interposed between the breccia and the Coal-measures were described in 1839 by Sir R. I. Murchison in the "Silurian System," and correctly referred by him to the Lower (New) Red Sandstone (or Permian) formation; and the following section, intended to give a general view of the succession of the beds from the Coal-measures to the New Red Sandstone inclusive, is nearly in the direction of the section illustrative of the rocks of this district as given in the third and fourth editions of "Siluria."‡

Fig. 4.

SECTION FROM NORTH TO SOUTH ACROSS THE CLENT HILLS.



C. Coal-measures. B 2. Permian beds with calcareous bands (× ×). 1. Permian breccia. A. Pebble beds of the New Red Sandstone.

The lower beds consist of red and purple sandstones (Fig. 2 B.) often calcareous, and containing bands which Sir R. Murchison describes as "earthy concretionary limestone (× ×) undistinguishable from some "of the cornstones of the Old Red Sandstone" and which have actually been burnt for lime. The whole of this lower series is about 600 or

* "On the Permian Breccia," &c.—Geol. Journ., vol. xi., p. 190.

† "South Staffordshire Coal-field," 2nd edit., pp. 184–5. As Mr. Jukes himself himself states, the writer "satisfied himself that the angular trappean breccia be-"longed to the Permian formation, and was a characteristic portion of it."

‡ "Siluria," 3rd edit., p. 301.

700 feet thick, and rests on upper Coal-measures, consisting of grey and greenish sandstones and trappoid conglomerates with red clays, in all about 1,000 feet in thickness, overlying the "thick coal" to the east of Stourbridge, as described by Mr. Jukes.*

A full description of this breccia is given by Professor Ramsay† in the memoir already quoted. In general appearance it is similar to that of the Enville country, the fragments of Silurian and other rocks being imbedded in hardened red marly paste. They are generally angular, or have their edges slightly rounded. The flattened sides of the stones are sometimes polished and occasionally scored, and in some cases reach a foot or more in diameter. They consist of felstone porphyry, greenstone porphyry, ribbon slate, black and green slate, red sandstone, quartz conglomerate and felspathic ash. But the most interesting specimens are those of Silurian sandstone and limestone, which, as they contain numerous fossils‡ have enabled Professor Ramsay to identify the locality from whence they have been derived. He says—"They do not resemble the "Caradoc beds of Walsall, Builth, Malvern, May Hill, or the Lickey, "but they are like the strata which rest unconformably on, and once "formed the beaches surrounding, the Longmynd and adjacent Lower "Silurian rocks." At the same time Mr. Jukes seems inclined to believe that many of these Llandovery sandstones "have not travelled "many yards from their original site, and that a boss, or peak, or ridge, "of Silurian sandstone lies concealed under the Permian rocks some-"where close by."§

A narrow strip of the breccia, underlaid by red sandstones and marls, occurs between two faults at Stourbridge, running along the edge of the coal-field. At Himley Park and Wolverhampton these beds occur in force, and at Baggeridge Wood there is an outlier of the calcareous conglomerate similar to that of Enville, near the base of the middle series of beds. On the east side of the coal-field the same rocks occur underlying the Pebble beds of the Trias and extending to the boundary fault of the coal-field. At West Bromwich they have been penetrated in several shafts and borings, details of which are given by Mr. Jukes. In Lord Dartmouth's coal-pits they were found to be 806 feet in thickness, resting unconformably on the Coal-measures, and in this district Mr. Jukes considers there is not less than 1,530 feet of these beds.‖ Good sections are shown in the cuttings of the Birmingham and Dudley Railway; and the same band of calcareous conglomerate which occurs along the northern flanks of the Clent and Lickey Hills is also found on the east side of the coal-field at Barnford Hill, where it is 20 feet thick, and at Great Barr.

The highest beds of the Permian series in this district are those of trappoid breccia, the strata which overlie this breccia in the Enville country being here apparently overlapped by the New Red Sandstone along the southern slopes of the Clent and Lickey Hills. Further north along both sides of the coal-field, these latter beds are themselves overlapped, and the New Red Sandstone rests on the lowest of the three

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* "South Staffordshire Coal-field," 2nd edit., pp. 28, 29.

† Geol. Journ., vol. xi., pp. 190, 191.

‡ Mr. Salter has given the names of a number of species from these fragments, ibid. p. 191.

§ Ibid. p. 9. The recent discovery of Silurian beds forming a bank rising to the south near Hales Owen seems to confirm this view, but many of the blocks of other rocks doubtless have travelled from a distance, as Professor Ramsay states.

‖ "South Staffordshire Coal-field," 2nd edit., p. 12.

groups into which the Permian series is here divisible. There is therefore clear evidence of the unconformity of the Triassic and Permian beds in this as in the Enville and Bridgenorth districts; on the other hand, the extensive denudation of the Coal-measures at West Bromwich anterior to the deposition of the Permian beds, and the discordant superposition of the two formations, show that these "red beds," although in places bearing a certain resemblance to the formations both above and below, are a very distinct and self-existent group.

Relative Position and Origin of the Conglomerate and Breccia.—The breccias and conglomerates are distinct from each other, not only in the composition and form of the component rock-fragments, but also in stratigraphical position. The conglomerates are on a lower horizon, the breccia is on a higher; and the identity of the latter in the districts of Enville, Bewdley, Wars Hill, Stagbury, Church Hill, Woodbury Hill, in the neighbourhood of the Abberley and Malvern ranges, with the breccia of the Clent Hills, as shown by Professor Ramsay, is perfectly clear on stratigraphical grounds. The composition of the fragments has led the same author to trace their sources to parts of Shropshire and Montgomery, lying from 20 to 30 miles distant in the region of the Longmynd and the Stiper Stones, as well as some of the Carboniferous tracts of the Clee Hills and Coalbrook Dale.

As regards the original extent of this breccia, Professor Ramsay estimates that it covered an area of not less than 500 square miles. How much more it is impossible to say, its northern limits being uncertain in the direction of Bridgenorth and Wolverhampton, as also are its eastern limits in Worcestershire, owing to the overspread of the Triassic formation. On the Clent and Bromsgrove Lickey Hills, the breccia attains elevations of 800 or 900 feet above the sea-level, and on the Abberley and Malvern ranges, it is from 800 to 1,000 feet in its highest positions. These elevations are not very much under those of the Longmynd, Stiper Stones, and Corndon Hills, which only rise from 1,500 to 1,700 feet, and from which those breccias are considered to have been derived by the agency of ice drifting away from glaciers. Professor Ramsay has seen the force of this objection to his theory, but meets it in a satisfactory manner by pointing to the great fault which traverses the country between the districts occupied by the breccias and their supposed parent rocks. This fault, which ranges from Gladestry in Radnorshire by Church Stretton and Acton Burnell to the banks of the Severn is a downthrow of about 2,000 feet. If the country was restored to its original position before the displacement by the fault, the effect would be to elevate the Longmynd Mountain to a position relatively 2,000 feet higher than at present; a position involving no improbability as regards the existence of glaciers descending into the sea, and sending off rafts of ice laden with boulders and gravel to the southward.

District East of Coalbrook Dale, &c.—The Permian beds east of the Coalbrook Dale coal-field have been very clearly laid open since the formation of the Shrewsbury and Wolverhampton railway. The eastern boundary fault of the coal-field is shown in one of the cuttings, where we find the following beds brought into juxtaposition:—

Upper Coal-measures.		*Permian.*		*Permian.*
Grey and bluish irregularly bedded sandstone.	Fault.	Red marls, &c., partly concealed by grass.	Fault.	Red and brownish speckled sandstone.

Proceeding eastwards we pass through two cuttings in similar beds of brown, purple, and red sandstones, irregularly bedded and containing layers of marl. Each of these beds of sandstone is underlaid by others

of red marl, which, as they occupy the intervening hollows, are not so clearly shown. The dip in both cases is eastward at 5° to 8°. Not far from the village of Haughton, near Shiffnal, calcareous conglomerate occurs, 12 feet thick, and traceable for about a mile from north to south, but thinning away before reaching the railway. This rock, formed principally of sub-angular or rounded pebbles of yellow Carboniferous limestone, sandstones, and grits of several kinds, white quartz, and jasper, is precisely similar to that already described near Enville and Stourbridge. It seems to terminate northwards against a large fault; but again appears under Lilleshall House, north of which, near Church Aston, the Permian formation is entirely concealed beneath the New Red Sandstone.

The Lilleshall Iron Company in their New Granville pits have passed into coal through the lower beds of this formation. It was stated at the time that the coal was discovered in spite of contrary expectations on the part of the Government Geological Surveyors. No grounds for such an assertion, however, existed, as might have been seen by reference to the horizontal sections,* which have been drawn across this district, and the "Explanations" of the geology which accompany them. It is quite true, no very dogmatic assertion of the presence of coal under the Permian beds was justifiable at the time the survey was made, as it had been found that the upper seams of coal die out eastward along a slightly inclined plane, and it was uncertain to what depth this plane might extend. Thus east of the "Lightmoor fault" the upper coals are all gone, and the "top coal" has been found to terminate at the Woodhouse Colliery 270 yards east from the pit.† Such facts as these would naturally make one cautious in speculation upon the extension of the Coal-measures, especially since Mr. Marcus Scott has shown the extensive denudation to which the lower beds of the Coal-measures were subjected before the deposition of the upper in this coal-field; but, according to the usual arrangement of the strata, the coal-seams ought to be found extending eastward under the Permian and Triassic formations.

The Permian breccia nowhere appears in the district east of the Coalbrook Dale coal-field, nor anywhere further north, and it is impossible to say whether or not it is concealed beneath the New Red Sandstone.

West Side of the Coalbrook Dale Coal-field.—Owing partly to the existence of the boundary fault which brings the New Red Sandstone in contact with the Carboniferous rocks, the Permian beds nowhere appear to the west of the coal-field. Their existence here, however, appears to be indicated by the results of a boring put down at Hadley Park estate, and communicated to me by Mr. H. Beckett, F.G.S. After passing through 53 feet of gravel and 69 feet of New Red Sandstone, strata described as "dark-red rock with mottled clays," and having a conglomerate at the base, were proved, and may be regarded as of Permian age; but instead of finding Coal-measures underneath, the boring-rods passed for a distance of 42 feet into "hard green rock," evidently trap, and possibly of Silurian age. The prospects of finding coal, therefore, west of the boundary fault have proved so far unsatisfactory.

Shrewsbury District.—Extending along the north side of the Shrewsbury coal-field occurs a long strip of Permian beds, similar to those

* Sheets 54 and 58.

† As I was informed by the manager, Mr. Edward Jones, on the occasion of a visit about eight years ago.

already described at the east side of the Coalbrook Dale coal-field. The beds appear a short distance west of Alberbury, and continue eastward by Shrewsbury to the base of the Cambrian rocks of Haughmond Hill. They consist of red and purplish sandstones, and deep red and purple marls and shales. Professor Ramsay and myself searched them carefully for fossils but without success, and owing to the depth and continuity of the drift deposits, sections are rarely visible.* The whole of these beds attain a thickness of 700 or 800 feet.†

The Permian series of this district acquires a peculiar interest from the occurrence of calcareous breccia and conglomerate, in great part dolomitic, and nearly 400 feet in thickness at Alberbury. This rock was described by Sir R. I. Murchison in the "Silurian System" as overlying beds of red and purple sandstones and marls now known to belong to the Lower Permian series or *Rothe-liegende*, and surmounted by New Red Sandstone. Notwithstanding the resemblance which the Alberbury breccia bears at first sight to the magnesian limestone of the north-east of England, especially as regards its position in relation to the other rocks, we must, I think, regard this rock, from the identity of the fragments it contains, and its position, as only the marginal representative of the calcareous conglomerates of Shiffnal, South Staffordshire, and the Enville country; the whole of which, in all probability, belong to the lower division of the Permian series. That the breccia is a limestone is only due, as it seems to me, to the accidental circumstance of the stones having been derived for the most part from rocks of that composition, but it is not a limestone of *primary formation* in the sense applied to that rock in Yorkshire and Durham.

This brecciated rock is composed principally of angular fragments of compact cream-coloured limestone, in a reddish sandy calcareous matrix, a few of the fragments being as large as a man's head. Some of these are of mountain limestone, and some belong to a peculiar band which Sir R. Murchison has traced for many miles in the upper coal-measures of this district, between the first and second coal-seams, and which in a pit at Pontesford was found to be seven feet in thickness. This is now known as the "*Spirorbis* Limestone."‡ Along with these are rounded pebbles of white quartz, chert, and pieces of slate in smaller quantity. The rock is quarried and burnt for lime, and also yields flagstones. It rises in the form of a low escarpment towards the south-west, curving in a semicircular form, and terminating abruptly at the edge of the alluvium of the Severn valley. In the direction of the dip, northwards, the beds are terminated by a fault against the New Red Sandstone. In the vertical joints strings of copper have been found. At Cardeston the breccia is apparently becoming thinner, and here it terminates against a fault, which passes close to the church in a northerly direction. East of this fault we lose all trace of this remarkable rock.

The breccia may be regarded as a Permian shingle beach, formed at the base of upraised Carboniferous and Silurian land, and, judging by the angularity of the pebbles, at a very short distance from the old

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* Sections are shown near the village of Walton in a quarry of sandstone, dip East at 10°; at Wytheford Bridge, and the banks of the river Roden. On reaching the banks of the Severn, near Shrewsbury, we find sections at the railway bridge near Preston in a quarry, and on the left bank of the river west of the town and in "The Quarry;" also at Red Hill, and in the banks of the brook above Lower Edgebold, and at Yokleton.

† See Horizontal Section of the Geological Survey, sheet 53.

‡ From the occurrence of the little annelide shell, *Spirorbis carbonarius*. See "Sil. Syst.," p. 83, wherein figures of the fossils (supposed then to be freshwater species) are given.

coast cliffs ; and, with the Carboniferous hills rising abruptly a few miles towards the north-west full in view, there can be little question regarding the position of this old coast.

The underlying beds, consisting of alternations of deep red marls and brown calcareous sandstones, resting on the Coal-measures, and attaining a thickness of about 750 feet, may be seen in a brook course at the base of the escarpment at Alberbury, and also at Pecknall.

Condover, South of Shrewsbury.—A small tract of Permian beds occurs in this neighbourhood, interposed between New Red Sandstone and Coal-measures, and bounded laterally by faults. The beds are precisely similar in character and position to those near Shrewsbury, consisting of red, purple, and brown sandstone and marls, with a general dip at a small angle towards the north-east. Sections may be observed in the cuttings of the Shrewsbury and Hereford Railway.

Oswestry and Wrexham District.—Between Alberbury and the southern extremity of the Denbighshire coal-field the Permian beds appear to be overlapped by New Red Sandstone, for at Wolstone this formation may be seen in a position only a mile distant from that of the Millstone Grit, and part of this space must be occupied by the lowest beds of the former. The first trace we obtain of Permian strata is at an old coal-pit close to the Llan-y-mynech road, the upper part of which passed through red sandstones supposed to belong to that formation. From this point, till we arrive at the banks of the Dee, the older formations are so deeply buried beneath beds of Drift gravel and clay as to be nowhere visible ; but the breadth of country they occupy along Dee-side below Pen-y-lan shows that they here occur in considerable force, probably not less than 1,500 feet, as shown by one of the Horizontal Sections of the Geological Survey.*

The beds consist of red and purple sandstones, sometimes thinly laminated, at other times massive, interstratified with thick beds of red marl. Calcareous concretionary sandstones, or earthy limestones, also occur, as at Gronwen Wood, overlooking the north bank of the Dee. The general dip is E.S.E. at 10° to 20°, and sections may be seen almost continuously from the base of these beds at Gronwen Wood along the banks of the river to Eyton Hall, and at Pant Mill along Shell Brook. The beds are traversed by a powerful fault ranging from west to east from the Vale of Llangollen, and coinciding with the general trend of the river as far as Pen-y-lan. It is a downthrow to the north of varying amount, lessening eastward.

The Permian beds near Ruabon rest on a very thick series of Upper Coal-measures, consisting of greyish sandstones and shales, with mottled red clays, and thin bands of coal, from 300 to 400 yards in thickness. A considerable portion of these measures have been penetrated in the New Hafod-y-bwch pits of the Ruabon Coal Company. They are well shown in the lofty cliffs which line the banks of the river Dee at New Bridge.†

Not far from Wrexham the river Clywedog affords us sections in Permian strata along its banks from below Kings Mill for about a mile downwards, beyond which the Drift gravels come down into the bed of the brook, entirely concealing the older rocks. They consist of pale red and purple sandstones, massive below, but becoming flaggy upwards, interbedded with red and purple marls.

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* Sheet 44, No. 2.

† See also "Vertical Sections of the Geological Survey," by Mr. D. H. Williams sheet 24.

From this point northwards the New Red Sandstone is considered gradually to overlap all the Palæozoic strata, until near Hope it is found resting directly upon beds belonging to the Millstone Grit Series (see fig. 17, p. 38). Owing to the absence of sections in the valley of the Alyn below Gresford it is uncertain whether any beds of Permian age are here interposed between the Trias and the Coal-measures; but the upper portion of this latter formation is well laid open to view in the banks of the river above Gresford Bridge, consisting of greyish and yellowish sandstones, with intermediate reddish and mottled clays; the whole dipping to the eastward at 5° to 10°.

The Upper Coal-measures and Permian beds east of the Denbighshire coal-field form a rich store-house for the future supply of mineral fuel. Throughout a distance of nearly 18 miles from north to south there is a steady dip to the eastward of the Coal-measures under the newer formations, combined with great regularity in the stratification. The coal-seams themselves are of excellent quality, and of fair thickness, and the distance to which they may be mined in the direction of the dip is only a question of depth.

Having now followed these beds to the banks of the Alyn, where they are lost to view in their north-westerly extension, let us retrace our steps into Warwickshire, and, taking the course of the Warwickshire, Leicestershire, and North Staffordshire coal-fields, complete the circuit of these Lower Permian beds. This course I prefer to that of describing the South Lancashire Permian beds; because, as it seems to me, they are of such an entirely different character that they ought more properly to be described by themselves, and not in connexion with the beds of the Central counties. The cause of this dissimilarity I will in a future page endeavour to elucidate.

Warwickshire District.—The Permian beds occupy a large area along the south and west of the Warwickshire coal-field from Baddesley Ensor on the north to Ashow on the south, a distance of 18 miles, and with a maximum breadth of six miles from west to east, north of Coventry. The western boundary is a fault, ranging north and south by Nether Whitacre for the greater part of the length, and giving place to another passing in a parallel direction by Kenilworth Castle. Along the south and east as far as Foleshill the beds dip beneath the Lower Keuper Sandstone, but north of this village, in the direction of Bedworth, they emerge, and, in company with the coal-measures, rise and crop out to the north-east. A small inlier of coal-measures with "*Spirorbis* limestone" is brought up along the line of a fault at Arley, nearly in the centre of the Permian area.

The Permian beds of this district were dissevered from the Triassic series by Professor Ramsay and Mr. H. H. Howell of the Geological Survey between the years 1851–54, and are very fully described by the latter in the "Memoir on the Warwickshire Coal-field."* From these beds were extracted by Dr. Lloyd the reptilian remains already referred to,† besides casts of a shell considered by Mr. Salter as allied to the Permian genus *Strophalosia*,‡ and silicified trees of the genus *Caulerpites* and *Breea*,§ and fragments of *Lepidodendron* and *Calamites*, found in a quarry near Exhall by Professor Ramsay, proving the Palæozoic affinities of these rocks.

The Permian beds resemble those of the lower series at Enville and in South Staffordshire, consisting of alternations of pale red, brown, and

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* Memoirs of the Geological Survey, 1859.

† Page 4.

‡ For figures see Mr. Howell's Memoir, p. 32.

§ In the Warwick Museum; no precise locality given.

purple sandstones, and red marl, with beds of calcareous breccia and conglomerate. These latter are generally in the lower part of the formation, and sometimes exist in continuous beds, but more commonly in lenticular masses, thinning out in every direction.

The breccias and conglomerates are sometimes so calcareous as to form an impure limestone. They contain pebbles of older rocks, and at Exhall were found pebbles of Silurian sandstone, probably of Upper Llandovery age, with *Atrypa hemispherica*, also fragments of Carboniferous limestone ; in the breccia near Polesworth were found pebbles of quartz rock and purple sandstone, some of which were several inches in diameter. The calcareous breccia may be well seen in quarries between Fillongley and Over Whitacre, also at Rush Flanders, Tibb Hall, near Coleshill, and Hurley near Baxterly ; the higher beds, in sections between Coventry, Kenilworth, and Warwick, at which last-mentioned town they were penetrated in a boring for water to a depth of 700 feet. The maximum thickness of the Permian beds in this district is estimated by Mr. Howell at not less than 2,000 feet.

No one, on examining the geological structure of this district, can doubt the westerly extension of the coal-measures beneath the Permian rocks ; and the appearance at Arley of the upper "*Spirorbis* limestone" shows that over a large area the depth of these beds is not great. The Permian area, therefore, may be regarded as a region destined to produce large supplies of coal in future years.*

Leicestershire Area (*Ashby-de-la-Zouch*).—The Permian beds in this neighbourhood are very sparingly represented, and can only be considered as *marginal* representations of the thick series of Warwickshire. They occur in a few spots, peeping out from beneath the Trias, along the west and south of the Carboniferous rocks, but are not found on the east side of the coal-field. The principal deposit is the breccia of Measham, composed of angular or rounded fragments of green slate, grits of several kinds, purple sandstones, chert, felspar trap (?), and quartz rock, all imbedded in a red marly paste. This rock is sometimes consolidated, and at Linton has been penetrated by borings which have gone down into the "main" coal underneath. The thickness of these beds is nowhere considerable, and it is clear that the original margin of the formation has been reached in this neighbourhood. I have given a full description of these strata in the "Geology of the Leicestershire coal-field."†

North Staffordshire District.—It was in this district, while surveying the "Red rocks" along the southern margin of the North Staffordshire coal-field in 1851, that I was struck by the distinctive peculiarities of the Permian and Triassic series, and where, after having traced the divisional line of boundary between the two formations in that locality, I came to a knowledge of the true relations of these bordering representatives of the Palæozoic and Mesozoic Epochs in the central and western counties of England.

The Permian beds rest with a slight amount of discordance upon the upper Coal-measures from Audley on the north-west to Blurton near Longton on the south-east, forming a band of country of varying breadth by Madeley, Keel, Newcastle, to Barlaston, near Stone. From Madeley they also stretch southward for several miles to Great Bolas in Shropshire, being brought to the surface along the line of a large fault near Cheswardine, which ranges in a N.N.E. direction. A fine section of

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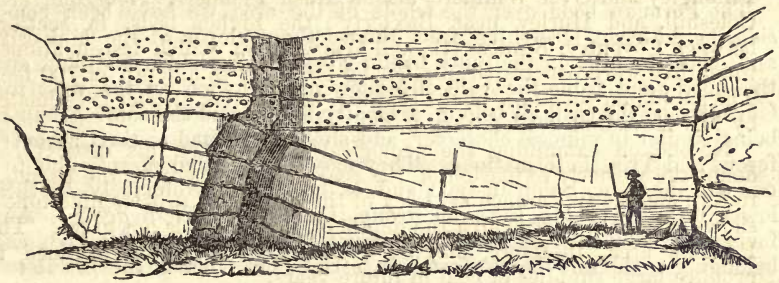
* See Horizontal Sections of the Geological Survey, sheets 48, 49, and 51.

† Memoirs of the Geological Survey, 1860, p. 57, *et seq.*

these beds, consisting of red and purple sandstones and marls, is laid open in the canal section near Cheswardine, together with the eastern boundary fault which introduces the conglomerate beds of the New Red Sandstone. A sketch of this section and the fault is shown in another page (see Fig. 26, p. 48.); and in a quarry at "the Loggerheads" the conglomerate of the New Red may be seen resting in an unconformable position on Permian Sandstone as shown in the following sketch, Fig. 5.

Fig. 5.

Unconformable Position of the New Red Sandstone and Permian Sandstone at "the Loggerheads."



The Permian beds south of the coal-field consist of red and purple sandstones, sometimes brown and mottled, with calcareous bands, interstratified with red marls. The calcareous bands are similar to the cornstones of the Old Red Sandstone. The total thickness of the formation is probably not more than 600 or 700 feet;* excellent sections may be seen at Keel, Newcastle-under-Lyne, Penkhull, Blurton, Trentham, Barlaston, and in the cuttings of the railway between Stone and Stoke. West of Newcastle the whole of the Permian beds are repeated by a large downcast fault ranging in a north-west direction through Trentham Park to Apedale. The upper Coal-measures on which they rest are very finely laid open in the cuttings of the railway between Stoke and Newcastle, and consist of yellow and greenish ashy sandstones with very thick beds of red and mottled clays, which are largely employed in the manufacture of tiles, bricks, and pottery.

In the Permian sandstones obscure impressions of plants are occasionally to be met with, resembling *Sigillaria.*

The Permian beds are overlaid unconformably by the quartzose conglomerates of the New Red Sandstone, which generally rise in steep rounded banks and ridges above the ground occupied by the older formation; this boundary may be traced from Knowl Bank, near Betley, southward by Heighley Castle, Bar Hill, Aston, Whitmore Hall, Hanchurch Heath, and Trentham Park southward to the north of Stone. Near Longton we find the same Triassic beds resting on Coal-measures, and this continues to be the case as we proceed eastward along the boundary of the coal-field by Dilhorn, Cheadle, to the river Churnet. There is clearly, therefore, a complete unconformable overlapping by the New Red Sandstone of all the Permian strata from west to east, which I have endeavoured to represent by a section in the chapter treating of the Triassic formation of this district (see Fig. 26, p. 49).

Extension of the Coal under the Permian Beds.—On considering the relations of the Permian beds to the Coal-measures along the southern

* See Horizontal Section of the Geological Survey, sheet 41.

and western margins of the coal-field; we find there is a steady dip of the two formations in the same general directions; and at Newcastle, Clayton, Hanchurch, and Trentham, where the upper Coal-measures are brought to the surface by faults, this fact is equally apparent. It is clear, therefore, that the whole of the coal-beds underlie these Permian rocks; and as their greatest thickness does not exceed 600 feet, and that of the upper Coal-measures 1,000, the depth to the "red shag" or the "bassy mine" ironstones would probably not exceed 600 or 700 yards over any part of the ground occupied by this formation, and over much of it would be considerably less. With such rich and valuable beds of ironstone and coal as this district contains it is satisfactory to know that there is a large area of productive ground still unbroached.*

The Permian beds over the whole of the area we have been considering hitherto, stretching from the northern slopes of the Malvern and Abberley hills on the south to the North Staffordshire coal-field on the north, and from the vale of Mersey near Ruabon on the west to Coventry on the east, all belong evidently to one and the same group; being similar in mineral character, and similarly related to the Carboniferous and Triassic formations. They may be regarded as referable to one and the same Salopian type, and as belonging exclusively to the lower member of the Permian group, the *Rothe-todte-liegende*. As far as our evidence extends, we cannot identify any of the beds as belonging to the middle, or *Zechstein*, series; but whether this is due to denudation, or to original absence of deposition, is a question on which there is little evidence to guide us. The beds of the same age we are now about to consider occurring in South Lancashire and Cheshire are, it will be found, highly dissimilar, and after having described them I shall have a few words to say on the causes of that dissimilarity.

Rushton Spencer near Leek.—A very small patch of Permian rocks occurs about five miles north-west of Leek, interposed between Yorkdale beds and New Red Sandstone. The beds are described by Mr. E. W. Binney,† and more recently by my colleague Mr. A. H. Green.‡ They consist of red mottled sandstones, sometimes thick bedded, with partings of marl, underlying chocolate coloured and white marls, the whole series being about 70 or 80 feet in thickness. These beds are, I think, more allied to those of North Staffordshire than to those of the Manchester district, and may be regarded as the marginal representations of the series of the Midland counties.

Part 2.

Lower Permian Beds of the Lancashire Type.

South Lancashire District.—The Permian beds in this district were first indentified and described in detail by Mr. Binney, F.R.S.,§ and more recently by myself in the Memoirs of the Geological Survey. They may be traced along the southern margin of the coal-field from

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* I have always had a high opinion of the resources of this coal-field, which contains coals of much excellence, and ironstone of greater thickness than in any other district. These beds are described in my "Coal-fields of Great Britain," 2nd edit., p. 115. See also Horizontal Sections of the Geological Survey, sheets 41 and 55.

† "On the Permian Beds of the North-west of England."—Mem. Lit. and Phil. Soc., Manchester, vol. xii.

‡ "On the Geology of Stockport," &c.—Mem. Geol. Surv., p. 36. Mr. Green supplies a woodcut illustrating a cross section of these and the underlying carboniferous beds, fig. 8, p. 36.

§ See *suprà*, page 7.

Sutton near St. Helens, by Haydock, Edge Green, Astley, Manchester, and Stockport into Cheshire, terminating at Poynton by the overlap of the New Red Sandstone to the line of the "red rock fault," which forms the boundary of the Poynton coal-field.

Mineral character.—As already stated these beds are of a type differing much from that of their supposed contemporaneous beds in the Midland counties and Shropshire. They consist of two divisions; the lower being formed of bright red and variegated sandstone of uniform composition, soft and without pebbles, and suitable for moulding purposes at foundries; the upper, of red marls with numerous bands of fossiliferous limestone, which have been worked for lime at Astley and Bedford. The fossils belong to the magnesian limestone genera, *Schizodus*, *Bakevellia*, *Turbi*, and *Tragos*. These beds are considered, with every probability, to be the representatives of the magnesian limestone of Yorkshire and Durham under a debased form, wherein the calcareous matter has given place to argillaceous sediment under differing conditions of deposition. They attain at Worsley a thickness of 131 feet with 52 thin beds of limestone.*

The Lower Permian Sandstone is well opened out to view at Collyhurst, Manchester, and in the banks of the rivers Mersey and Tame above Stockport.† In this neighbourhood it attains apparently its fullest dimensions, which I estimate at not less than 1,500 feet of bright red sandstone, obliquely laminated, of uniform texture and composition throughout; in striking contrast to the variable nature of their representatives in the Midland counties.

The Lower Permian Sandstone rests in a slightly discordant position upon the Coal-measures, gradually overlapping these beds from Manchester to Sutton, and then returning to higher beds, so as to allow of the reappearance of the "*Spirorbis* limestone" at Whiston. On the other hand, the Permian beds are themselves unconformably overlaid by the New Red Sandstone; these relationships of the three formations to each other I have endeavoured to express by the aid of a diagramatic plan in my Memoir on "The Geology of Bolton-le-Moors."‡

To the north of the Lancashire coal-field we again find these beds, belonging to the same type, at Skillaw Clough, in Bispham, at Clitheroe, and in North Lancashire and Cumberland, as shown by Sir R. I. Murchison, Professor Harkness, and Mr. Binney. Throughout this tract the formation is clearly of a character altogether distinct from the contemporaneous beds of the Midland counties and Shropshire.

I have thus completed the sketch of the Permian group over the district properly embraced within the limits of this memoir. It now remains for me to offer very briefly my views on the physical geology of the district over which these strata are spread, and to explain in more detail the cause, as it seems to me, of the extreme dissimilarity between the Permian rocks of South Lancashire and those of the Midland Counties.

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* "Geology of the Country around Bolton-le-Moors."—Mem. Geol. Surv., p. 20.

† "Geology of the Country around Stockport, Macclesfield, &c.," by Messrs. E. Hull and A. H. Green.—Mem. Geol. Survey, p. 33.

‡ See fig. p. 31.

CHAPTER III.

Physical Geology of the Early Permian Period of Central England and Salop.

At the close of the Carboniferous Period terrestrial movements of greater or less amount took place over the region of Central England and Wales, resulting in local elevations and depressions, and in some places in the removal by denudation of a large amount of the older rocks. The result appears to have been the formation of an inland sea (whether connected with the ocean or not it is impossible to say) into which were poured by streams, and, at one period, by ice-agency, the detritus of the surrounding lands. The margin of this sea may be traced without much difficulty in some directions. In West Shropshire it was formed by the Longmynd, Shelve, and neighbouring hills, at that time 2,000 feet higher (relatively) than at present. Traced southward it had probably a very indented outline, stretching perhaps as far as Carneddau and the Black Mountains.

Towards the north-east the margin was clearly in the region formed of the Cambrian rocks of Charnwood Forest, and it extended in a north-westerly direction by Leek to Congleton Edge; by this barrier, composed for the most part of Lower Carboniferous rocks, the Permian basin was dissevered from the region of the north-east of England, which we must suppose was dry land during the earlier part of this period.

So dissimilar are the Lower Permian beds of south Lancashire and those of the Central counties, that I think it is impossible to suppose they were formed in the same basin. I am therefore disposed to consider that the two basins were shut off from each other by a barrier or ridge of Carboniferous rocks upheaved at the close of the Carboniferous period, and extending from east to west underneath the central plain of Cheshire. The point where the ridge emerges from beneath the Triassic formations is indicated by the upheaval of the Lower Carboniferous rocks at the south of the Flintshire coal-field on the one side, and by the upheaval of the Yoredale beds in the valley of the river Dane to the north of Congleton Edge on the other. Such a ridge would have formed a barrier between the basin of the Permian rocks of Lancashire and Central England. This view is borne out by the fact that the east and west lines of elevation and depression of the north of England belong to the period anterior to the Permian.* Such a line of elevation is clearly indicated by the uprising of the mountain limestone of Derbyshire along its southern margin.

I may remind the reader that the supposition of a barrier dividing rocks of the same age, but of dissimilar mineral character, is not without precedent in British geology; for although such a barrier, owing to geological changes, has ceased to be visible, it seems the only satisfactory explanation of the dissimilarity between the Old Red Sandstone of Devonshire and that of Herefordshire, which were apparently contemporaneous formations.†

The southern margin of the Permian basin is hidden from observation by more recent formations, but it was probably formed at no great distance to the southward of the Permian areas of South Staffordshire

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* As is evident in Yorkshire; and, as I have endeavoured to show, in Lancashire also. See Author's paper "On the relative Ages of the Physical Features of Lanca-" shire."—Geol. Journ., vol. xxiv., p. 323, 1869. Brit. Association Report, 1868.

† See Author's paper on "The Evidences of a Ridge of Lower Carboniferous rocks crossing the Plain of Cheshire beneath the Trias."—Quart. Journ. Geol. Soc., vol. xxv., p. 171.

and Warwickshire by the uprising of the Old Silurian rocks, which formed a shelving shore and marginal boundary both to this formation and to the Coal-measures in that direction.

CHAPTER IV.

New Red Sandstone or Trias.

Bunter Sandstone.

Over the whole area of Central and Northern England, from the estuary of the Ribble southward through Cheshire and Shropshire to the valley of the Severn in Worcestershire, and from the region of Siluria to the plain of the Humber, the Bunter Sandstone has now been shown, by the detailed examination of the Geological Surveyors, to be divisible into three members, with distinctive lithological characters, as capable of identification as the three members even of the Lias, though depending for such identification altogether on inorganic evidence. These subdivisions, which were first published by the author at the meeting of the British Association in Liverpool, and illustrated by a section across the Peninsula of Wirral,* have been adopted by the Geological Survey under the following terms:—

Bunter Sandstone
3. Upper Red and Mottled Sandstone.
2. Conglomerate, or Pebble Beds (with a basement bed of calcareous breccia).
1. Lower Red and Mottled Sandstone.

The New Red Sandstone being the introductory stage of the Mesozoic, or Secondary, group of formations, and being also unconformable to those of the Palæozoic, or Primary, group, rests indiscriminately on any of the older formations, whether Silurian, Devonian, Carboniferous, or Permian.† Thus, in Shropshire and Leicestershire, we find these beds supported by Cambrian rocks; in Derbyshire and Lancashire by Carboniferous; and in the Midland Counties by Carboniferous and Permian. The amount of denudation also which the Palæozoic strata have undergone before the deposition of the Triassic series has been very large, amounting in some parts of Lancashire, Derbyshire, and Staffordshire to thousands of feet. Special instances will be noticed when we come to treat of these districts.

Upper Limit of the Bunter Sandstone.—Reverting to the consideration of the Bunter Sandstone, which forms the special subject of this chapter, we find it everywhere overlaid by the basement beds of the Keuper series, generally in the form of a conglomerate or breccia, resting on an eroded surface of the Bunter Sandstone, and in some places with a slight but unequivocal unconformity. Instances of this unconformity will be adduced; and I hope to be able to offer a sufficient explanation for the entire absence of the Muschetkalk in England, as afforded by the relations which the Bunter and Keuper series maintain towards each other.

Succession of the Sub-divisions.—The upper and lower stages of the Bunter Sandstone present on the whole similar characters, consisting of

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* See Rep. Brit. Assoc., 1854, Trans. of Sections, p. 86. The names of the subdivisions then employed, as first proposed by myself, have subsequently been modified as above.

† As pointed out by Professor Sedgwick more than 40 years ago.—Geol. Trans. 2nd series, vol. iii., p. 39 (1827).

fine grained soft sandstones, and are separated by a stage of conglomerate, or hard pebbly sandstone, which is much the most persistant of the three members. The general order of succession appears to have been as follows :—Over a very irregular bed of the sea (or inland lake) of variable depth, was deposited a series of fine sand of bright colour, coming from the north-west, and thining away eastwards and southwards. To these succeeded, at the commencement of the second stage, the formation of shingle-beaches along the coast-lines of Wales and Shropshire, which gave place to quartzose conglomerates, and these latter to a series of fine sands, which were continued up to the close of the period; the whole was then probably converted into dry land, while over parts of the continent the Muschelkalk was being formed in the open sea.

We shall now proceed to follow these beds step by step over those parts of England included within the limits to be treated of in this memoir.

In no part of the western counties is the order of succession of the sub-divisions of the Trias more clearly presented than in the neighbourhood of Shiffnal in Shropshire.* Along the cuttings of the Wolverhampton Railway all the sub-divisions of the Trias, together with the Permian and Carboniferous rocks, are opened out in their order of succession. Taken in detail there will be found a slight occasional displacement of the beds by north and south faults, but, neglecting these, the arrangement is nearly that shown in the wood-cut section (fig. 6).

Fig. 6.

General Section.—Shiffnal.

Permian Beds. New Red Sandstone.

This section represents what may be termed the typical configuration of the New Red Sandstone, which we find constantly repeated with various modifications. It consists of two escarpments or ridges, the lower (*b*) formed of the conglomerate beds of the Bunter, the upper (*d*) of the brecciated base of the Lower Keuper Sandstone, bordered by valleys (*a*, *c*) composed of the Lower and Upper Mottled Sandstones.†

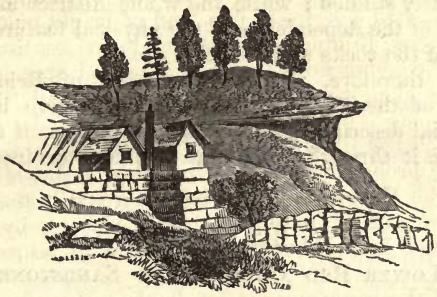
Precisely similar, but even more developed, is the order of succession which the rocks present upon traversing the country, commencing at the west side of Bridgenorth, and following the Wolverhampton road to a distance of about half a mile east of Hilton (Sheet 61, S. E.). Bridgenorth itself stands on a bold cliff of naked rock belonging to the Lower Mottled Sandstone close to its base, as we find the Permian strata rising from underneath, at a short distance from the town, on the Wenlock road. Following the course of the Wolverhampton road, we cross the Severn and ascend the hill to the lofty escarpment, which, ranging from Stockton to Gnatford in a direction due north and south, contributes towards the production of the bold and picturesque scenery for which the district is celebrated. At the top of the hill the road enters a cutting, excavated principally through the bed which crowns the escarpment; it consists of a hard calcareous breccia, which, from its firmness and durability, has contributed to the preservation of the ridge at its present altitude. The breccia here forms the base of the Conglome-

* Map of the Geol. Survey, 61 N.E.

† These features will be found drawn to natural scale in several Horizontal Sections of the Geological Survey. See sheets 54 and 58.

Fig. 7.

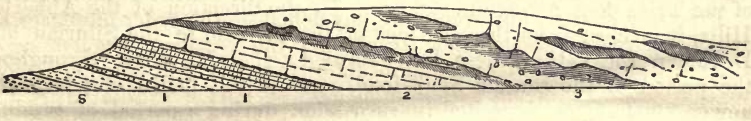
HARD CALCAREOUS BRECCIA AT THE BASE OF THE CONGLOMERATE BEDS NEAR BRIDGENORTH.



rate beds, and its junction with the Lower Mottled Sandstone is shown in the cutting. This bed frequently stands prominently forward, as in the cliff seen from the road, from which the above sketch (fig. 7) is taken, and is succeeded by some soft red sandstone, which may be seen in the valley of the Worf, along with the higher beds of the Conglomerate subdivision, consisting of reddish-brown sandstone with scattered pebbles. Half a mile west of Roughton we reach the Upper Mottled Sandstone, which may be seen at this village, as also at Worfield. Of these beds the whole country around Hilton is composed as far as the ridge which rises to the east of the village. This ridge is formed of Lower Keuper Sandstone resting on the soft sandstone of the Bunter. In order, however, to see these beds to advantage it is necessary to proceed to the next ridge to the eastward which the road crosses near Shipley. Both these ridges are composed of the same beds repeated by a longitudinal fault, and this is proved by the fact that in both cases the beds are overlaid by strata of the New Red Marl.

Fig. 8.

SECTION SHOWING THE JUNCTION OF THE BUNTER AND KEUPER DIVISIONS OF THE TRIAS AT SHIPLEY, SHROPSHIRE.



The section in the Wolverhampton road at Shipley offers an excellent opportunity for examining the junction beds of the Keuper and Bunter series (see fig. 8). The uppermost beds of the latter consist of bright red fine-grained soft sandstone, somewhat laminated (*s*.). Upon this come beds of slaty marl, interstratified with thin-bedded white sandstone (1), forming the base of the Keuper series. This is surmounted by hard calcareous light red sandstone (2) and an irregular bed of marl, which is succeeded in turn by hard calcareous mottled sandstone and conglomerate (3), with irregular patches of softer rock in places. Between this section and Shipley the upper beds of the Lower Keuper Sandstone follow in order, but are not well shown at this spot; and we also have the series complete, as strata referable to the Red Marl series are found in a brickyard north of the village.

I have thought it necessary to prove the order of succession in the sub-divisions of the New Red Sandstone in this neighbourhood, because

it may be regarded as a typical district, with which all others may be compared. Here all the sub-divisions attain a good development; their order of superposition can be demonstrated; and on account of the number and excellence of the sections their lithological characters may be advantageously studied; while the whole district affords a striking exemplification of the dependence of the physical features of the surface on the nature of the rocks underneath.

Considering, therefore, the neighbourhood of Bridgenorth as the typical locality of the Trias for England, I shall give in the following chapters a special description of each sub-division as it there occurs, and afterwards trace it through its various modifications into other districts.

CHAPTER V.

Lower Red and Mottled Sandstone.

Bridgenorth.

This sub-division attains at Bridgenorth a thickness of about 650 feet, as ascertained by a horizontal section which crosses the district from west to east.*

It rests unconformably on Permian sandstones and marls, which it overlaps to a considerable extent, but in a less degree than at Stockton, six miles farther north, where the Bunter Sandstone is separated by only a few feet of Permian beds from the Coal-measures. The extent of this overlap may be estimated at about 1,000 feet at Bridgenorth, for near Enville no less than 1,500 feet of Lower Permian beds intervene between the New Red Sandstone and Coal-measures.† This rapid overlap is due to the unconformity of the Trias and Permian formations.

The Lower Mottled Sandstone may be described as a mass of rather homogenous sandstone, of reddish brown, yellow, and bright red colours, almost approaching vermilion, and entirely devoid of pebbles. It may be traced at intervals from the estuaries of the Mersey and the Dee southward along the borders of Wales and Shropshire, where it rests sometimes on Permian, sometimes on Carboniferous, or even older, formations, to the banks of the Severn at Bewdley, where it terminates along a line of fault against the Permian beds of Warshill and the Coal-measures of the Forest of Wyre; and dipping beneath the higher beds of the Trias does not again emerge. In the direction of the Abberley Hills, it is clear from the relations of the Triassic to the Silurian and Devonian rocks, that these latter formed a shelving shore throughout the period of the Bunter Sandstone, against the flanks of which the newer strata were deposited in succession during a period of gradual submergence; on this account the lower members of the Triassic group are lost to view. Thus we find the Pebble beds brought into contact with the Palæozoic rocks along the banks of the Severn at Stagbury Hill, though at this point the boundary is to some extent a fault as stated by Professor Ramsay. Still further south the Lower Keuper Sandstone and Upper Mottled Sandstone of the Bunter repose against the shelving sides of the Abberley Hills, and still further south the Red Marl abuts against the Silurian and Devonian series, owing to the combination, as Professor Phillips has shown, of an ancient cliff and a more modern line of fracture. After losing the Bunter Sandstone along this original margin, it no more reappears north of the Severn, for we find the lower beds of the Keuper resting on the Carboniferous rocks, as

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* Hor. Section, sheet 54. † See ante, p. 13.

shown in the coast sections along the Bristol Channel, near Chepstow (see Fig. 33, p. 68).

The Lower Mottled Sandstone extends eastward but a short distance from the western outcrop. Thus it does not emerge along the line of the Triassic and Permian rocks on the west side of the South Staffordshire coal-field, for both at Rugeley and Beaudesert, Wolverhampton, and along the Clent and Lickey Hills, the Pebble beds rest directly on the Upper Palæozoic rocks (see Fig. 4, p. 17).

*Bewdley and Wribbenhall.**—The Lower Mottled Sandstone occupies the bed of a wide and irregular valley of nearly oval shape, enclosed along the east and south by the escarpment of the Pebble beds, and on the west by the Permian strata of Warshill. From Bewdley Bridge to the Hermitage it forms the banks of the Severn, and is very finely opened out to view in the river cliff and the sections made by the roads in crossing the escarpment of the overlying division. This valley is remarkable for the almost entire absence of brooks, as all the rain that falls over its surface is absorbed or evaporated ; on this account, the rock may be supposed to form of itself a well stored natural reservoir which could easily be made available by means of wells. At the northern apex of the valley the escarpment of the Conglomerate subdivision gradually trends towards the north-west, and abuts against the Permian breccia of Warshill Camp. In the hollow below, a mass of naked rock, somewhat of the form of a huge prostrate wedge, known as "the Giant's Grave Rock," rises prominently into view. As this is a brookless valley, some geologists might regard this rock, as well as the line of escarpment which overhangs it, as monuments of marine denudation.

For a distance of a mile northwards the Pebble beds still continue in contact with the older rocks along the line of the large fault already alluded to, but at Cornhill Coppice they break away from the fault, and form a fine terraced escarpment, sweeping round to the east by Horsley Bank, and northward to Kinver Edge. This escarpment overlooks a broad valley of Lower Mottled Sandstone, bounded along the west by the rising ground of Permian, Carboniferous, and Devonian rocks south of Enville.

One of the most remarkable features in the Lower Mottled Sandstone is the oblique bedding (the result of currents), which here attains a great degree of intensity. Lines marking such planes of current-lamination may occasionally be observed to preserve their parallelism for a distance of 50 yards and upwards.

Although the directions towards which the laminæ incline (or dip) are various, yet, with regard to the laminæ themselves, there is a remarkable degree of regularity. The road which connects the higher and lower towns of Bridgenorth winds round the southern face of the cliff, which is surmounted by the leaning ruins of the old castle. In this position the current-bedding has an inclination to the S.W. for a distance of at least 80 yards, at an angle of about 30°, and the striæ preserve a degree of parallelism unsurpassed by the true bedding of the most regularly stratified sedimentary rock.

A similar instance occurs in the cutting of the Wolverhampton road near its entrance to the lower town. The slope of the laminæ is also towards the south-west, at an angle of 25°. The parallelism of the planes of lamination is remarkably continuous for a space of 120 yards, with a vertical section of about 30 feet. An equally good illustration may be observed along the Kidderminster road south of Gnatford, near Comer Wood.

* This district was surveyed by my colleagues, Messrs. Aveline and Howell, under the direction of Professor Ramsay, and is illustrated in the Geological Survey Map, 55 N.E., and the Horizontal Section, sheet 50.

The *vertical depth* of these "*tiers of parallel lamination*," as they may be termed, is generally limited to 20 or 30 feet. Each is succeeded by another, the laminæ of which assume a different direction, being either horizontal, or dipping in directions more or less differing from those of the contiguous tiers.

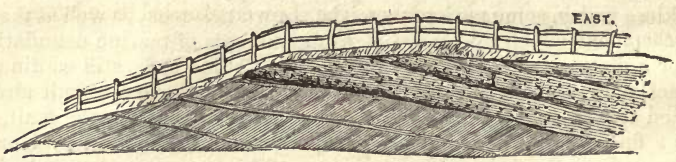
The dividing planes between the tiers are often as even and straight as if planed off by an instrument. I have no doubt but that these planes indicate approximately the true bedding of the rock, as is evinced by the Shiffnal section ; and also that their evenness arises from the planing or levelling influence of the subsequent currents either running in the same, or opposite, directions (ebb and flow), and too swift to permit of deposition.

I would also suggest, as an explanation of the direction of the oblique lamination being generally towards the south-west, that it is perpendicular to the line of ancient coast. The coast line would doubtless influence the direction of the main current, which, in its turn, has left an index of its course in the strata.

Another instance of current-bedding is brought to light in one of the sections of the railway east of Shiffnal, to which I have already referred. Here (as is represented in the adjoining sketch) we find a system of lines

Fig. 9.

Section in Railway near Shiffnal, showing the superposition of the Pebble Beds and Lower Mottled Sandstone.



marked by white streaks sloping towards the west for a distance of at least 200 yards, while the true dip of the rock is that marked by the line of junction with the Conglomerate beds.* Here this subdivision assumes its more usual character, being softer and of a finer grain than at Bridgenorth, where it has occasionally been quarried for building stone. One of these quarries is situated at the base of Pendlestone rock. Along the escarpment of Kinver Edge, 550 feet above the sea, the top beds are so hard as to project beyond the breccia which rests upon them. This firmness occasionally arises from the presence of a calcareous cement which has probably been infiltered from the superincumbent calcareous breccia which forms the base of the Conglomerate subdivision.

Fig. 10.

Cliff near Kinver Edge.

Many sections showing the junction of the Lower Mottled Sandstone and Pebble beds occur in the neighbourhood of Bridgenorth, all of which indicate that it is definite

* This variegation is noticed and represented by Mr. G. Maw, F.G.S., in his essay on variegated strata, Journ. Geol. Soc. vol. xxiv., p. 363, fig. 41, and from the following analysis of specimens taken from the red and pale bands it would appear that the difference in colour is due merely to the differences in the proportions of the sesquioxide of iron, not in a change of chemical composition. Thus it was found that in the red ground the proportion of sesquioxide was 1·30, and in the pale 0·40 in 100 parts.

and well marked. In general, however, the line is found to be very irregular, the breccia being deposited over a series of small furrows and ridges of an eroded, or waterworn, surface of the Lower Mottled Sandstone.

The section exposed in the road between Shiffnal and Bridgenorth, close to the bridge over the Worf, of which a sketch is annexed (fig. 11),

Fig. 11.

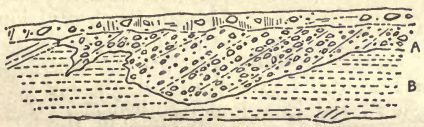
Sketch showing the superposition of the Conglomerate, or Breccia upon the Lower Mottled Sandstone.

is a good illustration of the phenomena of erosion which are pretty general all over the country.

The calcareous breccia does not extend many miles in an easterly direction, for in the road section between Stourton and Stourbridge (fig. 12) we find the quartzose conglomerate, which occupies a higher position, resting immediately on the Lower Mottled Sandstone. The

Fig. 12.

Section in Road near Stourton.



A. Conglomerate base of pebble beds. B. Lower Mottled Sandstone.

line of junction here is also very decided, and would seem to indicate that a considerable interval must have elapsed between the deposition of the one set of beds and that of the other. In the bank at the south side of the road a remarkable example of irregularity in the line of junction is presented. In the sketch of the section above the proportions are accurately given (fig. 12). It is clear that in this district the Lower Mottled Sandstone had undergone a considerable amount of local erosion before the deposition of the beds of the succeeding stage.

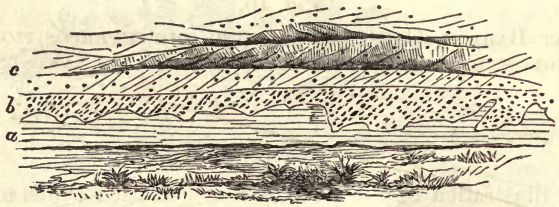
Inconstancy is a feature which characterizes the sub-division of the Lower Mottled Sandstone. We can trace it as far as the western boundary fault of the South Staffordshire Coal-field at Stourbridge, and as far north as Kingswinford, but on the eastern side of the coal-field near Birmingham it is absent, and the beds which there form the base of the New Red Sandstone are the quartzose conglomerates of the succeeding stage, which may be seen at Smethwick reposing on the Permian sandstone in the railway cutting. At Upper Pen near Wolverhampton, and along the southern margin of the Clent and Licky Hills, the Lower Mottled Sandstone has also disappeared; nor is it again known along the western or northern side of the South Staffordshire Coal-field.

This sub-division occupies a large area, extending from the west side of the Coalbrook Dale Coal-field to Shewsbury, and northward

to Hodnet. Throughout the greater portion of this country the formation is thickly overspread by Drift; yet wherever sections in the strata occur, they are found to preserve the same features which characterize them in the neighbourhoods of Shiffnal and Bridgenorth. Several sections showing the junction of the beds of this sub-division with those of the Conglomerate may be seen at the river cliffs of Eyton; also at Edgmond, and Shray Hill in the valley west of Great Bolus, of which a sketch is given (fig. 13); also at Childs Ercal, around Market Drayton,

Fig. 13.

SECTION AT GREAT BOLAS.

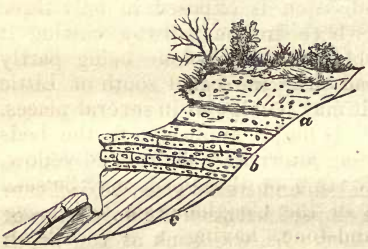


a. Lower mottled sandstone. *b.* Pebble beds obliquely deposited.
c. Coarse brown sandstone, with scattered pebbles.

and Drayton Common. In a quarry at Robaston Bank they are seen faulted against the coarse and harder sandstones of the Conglomerate sub-division. In the canal to the south-east of Market Drayton at Stony Ford, an almost continuous section from the base of the Lower Mottled sub-division well into the Conglomerate beds is laid open; the dip is westward at about 4°, which gives 70 or 80 feet as the thickness of the former sub-division in that locality. The section at Childs Ercal is remarkable for showing a thin bed of pebbles in sandstones which appear to belong to the Lower Mottled Sandstone. In the following section (fig. 15,) this bed (*x*) is shown. Its position

Fig. 14.

SECTION AT HELSHAW GROVE.

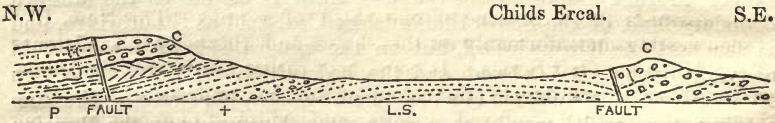


a. Soft rock, with pebbles.
b. Gravel beds (Conglomerate).
c. Lower mottled sandstone.

Fig. 15.

SECTION THROUGH CHILDS ERCAL, SHROPSHIRE.

N.W. Childs Ercal. S.E.



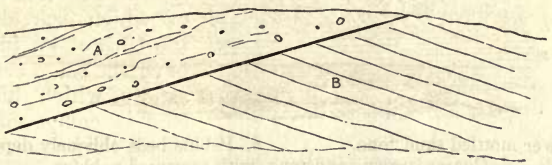
P. Permian. L.S. Soft variegated sandstone. C. Pebble beds.

is nearly 30 feet underneath what would otherwise be the true base of the Conglomerate beds (*c*), from which it is separated by a series of soft red and purple sandstones without pebbles. There is, however, no positive certainty that the lower pebbly bed may not be the true base of the sub-division.

Between Shrewsbury and Alderbury several sections in the Lower Mottled Sandstone may be seen, but so deeply is this whole country in general buried in Drift gravel, that but few sections are exposed, and the boundary of the Permian and New Red Sandstone is consequently very uncertain. At Knockin, near Oswestry, the Holyhead road cuts through a fault between the Conglomerate and the subordinate sub-divisions, and at Osbaston a junction between the two sub-divisions is exposed to view ; but as we proceed northward, owing to the Drift deposits, no similar instance can be observed till we arrive at Barton in the neighbourhood of Malpas, where in a quarry we are fortunate in

Fig. 16.

Sketch at Barton, Cheshire, showing the superposition of the Conglomerate Beds and Lower Mottled Sandstone.



A. Pebble beds.
B. Lower Mottled Sandstone traversed by planes of current-lamination.

lighting upon a junction, in which the Lower Mottled Sandstone presents that *apparent* unconformity which we have already recognized as frequent in the Shiffnal and Bridgenorth districts, and which, as has been shown, is due to current-bedding.

In the district of Chester, this sub-division is exposed in only three places, viz., at Waverton station, where in the railway cutting it may be seen faulted against the Pebble beds, its colour being partly white and partly red ; also in the road near the canal south of Little Mollington ; and at Hapsford, where it may be viewed in several places. In this locality the term "variegated" is highly applicable to the beds of this sub-division, the sandstone being alternately white and yellow, or blotched and streaked with red. Resting on these beds may be seen in the centre of the village the base of the Conglomerate beds, consisting of coarse and hard red sandstone, having a few pebbles scattered through the mass. Further north along the sea-beach below Ince Hall, fine sections in the beds of the two sub-divisions are exposed, together with a fault which throws down the Conglomerates on the west side against the Lower Red and Mottled Sandstone.

By far the finest section in the neighbourhood of Chester is that shown along the banks of a brook at Cuckoo Hill, north-east from Hope. Here we have a continuous view of the rock from the basement upwards for a distance of one third of a mile. The New Red is seen resting unconformably on the shales and thinbedded sandstones of the Millstone Grit Series. It consists of rather coarse soft sandstone, passing from a dark purple (the colour of the rock underneath) upwards through all the shades of red, yellow, and white. The change from white to red is often instantaneous, and does not always take place along horizontal, but sometimes inclined, and even vertical lines, having in fact no apparent connexion with the stratification. It is evidently a change subsequent to the deposition of the beds, arising from the partial withdrawal of the sesquioxide of iron. Occasionally, as at Bridgenorth, the laminæ of oblique-bedding, preserve an exact parallelism for several yards. The beds at the base of the sub-division

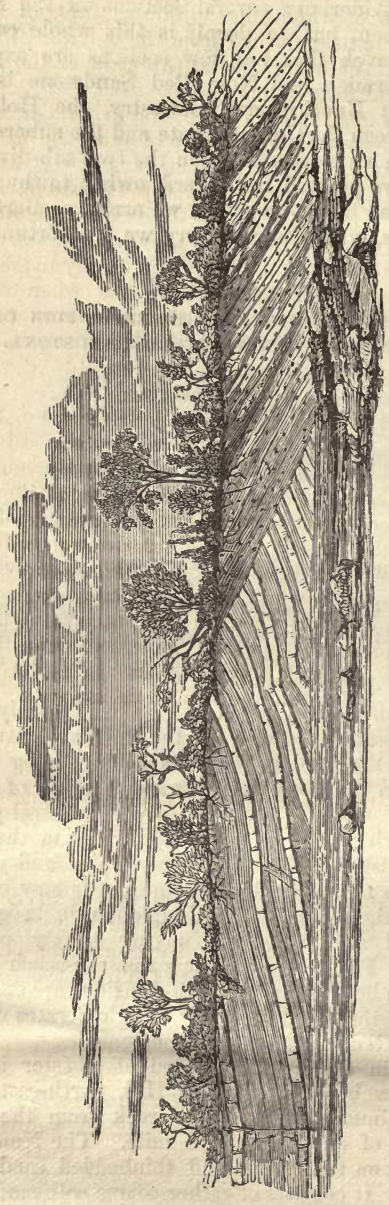


Fig. 17.
Brook Section near Hope, Flintshire.

require special notice. The lowest consist of a dark purple arenaceous breccia 10 feet in thickness, full of fragments of the underlying grits, and small rounded pebbles of white quartz. The latter diminish in size as they recede from the base, till they become the minute particles of sand which constitute the great mass of this sub-division. It is therefore probable that the white quartz pebbles, the largest of which scarcely exceeds the 10th of an inch in size, have the same origin as the sand of which this sub-division is composed. Besides these, the basement bed contains bands and nodules of conglomeritic and concretionary ironstone. The former has a metallic lustre, and consists of masses of small quartz pebbles cemented by, and thickly coated with, peroxide of iron. The latter variety has a rusty appearance, and more compact structure. In the beds higher up all traces of iron ore and fragments of rock are lost. The sub-division then assumes its characteristic features.

Whilst examining this section I could not but be impressed with the conviction that these basement beds of the New Red Sandstone were not of local origin, but that the sandy sediment of which they were formed was transported from a considerable distance. How else can we account for the fact, that in a mass of sand attaining a thickness of from 600 to 800 feet, no fragments of other rocks have hitherto been found? Along the section we have been examining, and in close proximity with this formation, we have, indeed, an illustration of a deposit of *local* origin, the Drift, and the contrast is too striking to be overlooked. The latter forms the upper portion of the river's banks, and consists of a mass of semi-angular gravel derived from the Carboniferous and Silurian rocks of the Welsh hills; while the New Red Sandstone is composed throughout of particles of well rounded quartz, averaging the size of mustard

seed, and, therefore, of a composition differing from that of the greater portion of the Palæozoic rocks of which the adjoining tracts of Wales are formed. Had this sandstone been formed from the detritus of rocks not far remote, we should expect to find, as in the case of the Drift, imbedded fragments of the local formations.

The Vale of Clwyd offers a good illustration of the manner in which the New Red Sandstone was formed along the base of sub-ærial districts of the more ancient rocks, filling in the arms and bays of the Triassic Sea. The bottom of this valley is composed of soft sandstone, in all probability belonging to the Lower Soft Red sub-division which we may suppose to be continuous with the Cheshire beds round the flanks of the Flintshire Coal-field underneath the sea. The vale is deeply overspread with Boulder clay, so that few sections are afforded, and when viewed from the north the bounding hills present a succession of abrupt spurs of Silurian and Carboniferous rocks closing in the valley in the distance, and which it requires no strong imagination to convert into the coast cliffs of the Triassic period when the sea filled the plain.

In the Peninsula between the Mersey and the Dee, the Lower Mottled Sandstone breaks out from below the Drift, at the village of Burton, its junction with the Pebble beds being visible. At Burton Point on the coast there is a still finer section. Commencing at the Point and walking northwards we cross over higher beds of the Lower Mottled Sandstone, till we arrive at the base of the Conglomerate sub-division (fig. 18). The former consists of interstratified hard and soft beds of various shades of red, yellow, or white, without pebbles; but upon arriving at the line of junction great quantities of quartzose pebbles suddenly make their appearance, and continue more or less abundant all along the section. These extend nearly across the strike for a distance of 350 yards, giving (with the dip of from 22° to 25°) a thickness of 400 feet, which is less than the total amount as the highest beds are concealed from view. Farther north the beds are thrown down by a fault against the Coal-measures.

Similar cases of superposition are visible at West Grange Hill, West Kirby, and at Eastham on the banks of the Mersey.

Along the southern borders of the Lancashire Coal-field this sub-formation sometimes appears in considerable force, as at Rainford, Whiston, and Halsnead, and the eastern border of the small coal-field of Croxteth Park; while a few miles farther to the east it entirely disappears, and at Ashton-in-Makerfield the Conglomerate beds rest directly on the Coal-measures. At Edge Green Colliery the pumping shaft actually passes 75 yards through hard pebbly sandstone of this subdivision before reaching the Coal-measures.

The section in the Manchester and Liverpool Railway between Rainhill and Whiston is interesting, from the variety of beds, and the number of faults it exhibits. After passing the boundary fault of the coal-field east of Whiston, the section cuts through soft yellow sandstone, obliquely bedded and jointed, belonging to the Lower Mottled Sandstone of the Bunter. Beyond this we cross a second fault bringing up a series of purple shales and sandstones of the Coal-measures, and extending a distance of 180 yards; these are again terminated on the east by a third fault throwing down orange-coloured sandstone of the Upper Mottled sub-division of the Bunter, and from below these the Conglomerate beds rise to the surface at rather a high pitch, and form a band of elevated ground west of Rainhill.

At Rainford a fine section in the beds of this formation has been laid open in the Ormskirk and St. Helens Railway. It extends for a distance of half a mile south of Rainford Station, at which point the rock is cut off

Fig. 18.

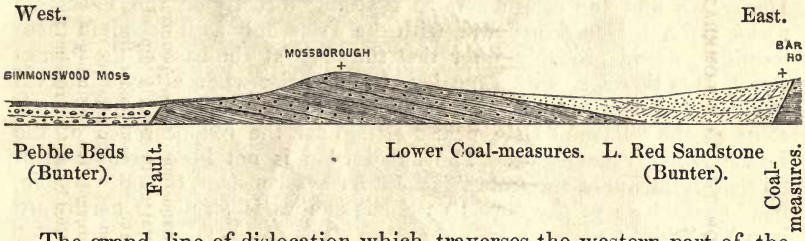
COAST SECTION AT BURTON POINT, CHESHIRE, SHOWING THE JUNCTION OF THE CONGLOMERATE AND LOWER MOTTLED SANDSTONE.* (See page 39.)

* It is scarcely necessary to remark that, wherever the rock is composed of Lower Mottled Sandstone in the peninsula between the Dee and Mersey, that position is the most favourable for sinking in search of coal. Moreover, the general north-easterly dip of the Flintshire coal-field, together with the existence of the coal-field near Neston, point to the probability of the continuance of coal under the entire peninsula. As the Coal-measures of Neston are brought to the surface by a fault, we are deprived of information as to the presence or absence of Permian strata. At any rate, the unconformity of the New Red Sandstone to the Coal-measures and Permian prevents the possibility of speculating with certainty upon the depth of coal below the surface, further than by remarking that, wherever the Lower Mottled Sandstone reaches the surface, the thickness of the New Red Sandstone is not greater than 500 feet, and generally less.

by a fault which appears to be a branch from the great boundary fault of the coal-field. The rock consists of soft, bright-red, orange, and yellow sandstones, streaked and mottled, and much affected with current bedding. North of Rainford Station the band is terminated by an east and west fault, and the beds appear to rest on the lower Coal-measure sandstone of Mossborough. A section through Mossborough Hall would probably be represented by the following woodcut.

Fig. 19.

Section near Rainford, Lancashire.



The grand line of dislocation which traverses the western part of the Lancashire coal-field from north to south, and skirts the western base of the range of Lower Coal-measures of Billinge and Ashurst beacons, throws in a small tract of this basement subdivision of the New Red Sandstone, which may be seen in several brook sections west of Holland Moor. The fault traverses the edge of Grimshaw Delf, which is excavated in the highest beds of the Millstone Grit, against which, on the opposite side of the fault, we find the bright red soft sands of the Lower Mottled Sandstone, locally called "red ore," brought into juxtaposition. The throw of the fault cannot here be less than 1,000 yards. It should be stated, however, that Mr. Binney refers the red sandstone both here, and at Rainford, to the Permian period; but, isolated as are the beds here, there can be no certainty regarding their age.

The Lower Mottled Sandstone occurs at St. Helen's Junction near Parr, resting on Permian marls; the thickness here does not exceed 250 feet. It again occurs at Eccleston Hall; and east of Prescot it is faulted against the Coal-measures. Eastward of this neighbourhood it does not again appear, as it is not represented at Astley, Bedford, Manchester, or Stockport. In these districts the Pebble beds form the base of the Triassic series.

We must now retrace our steps into Shropshire and Staffordshire. It has been already remarked that between Market Drayton and Whitmore the lowest subdivision of the Bunter does not appear. Around the Loggerheads, Trentham, and Stone, the quartzose conglomerate forms the base of the New Red Sandstone. In the neighbourhood of Madeley and along the base of the conglomerate ridges, south-west of Whitmore Station, certain beds of soft red and white sand occur, never exceeding 20 feet in thickness. I am uncertain whether these are to be considered as belonging to the Lower Mottled Sandstone, but as they occasionally contain small pebbles and are very unimportant either in superficial extent or in thickness, it has been thought safer to include them on the map with the conglomerates. However, at Merelake, near Alsager, the Lower Mottled Sandstone undoubtedly makes its appearance, and attains a thickness of at least 100 feet. In the lane which crosses the hill a section showing the soft red sandstone belonging to this subdivision rising from below the quartzose conglomerate is exhibited, of which a sketch is here subjoined.

Fig. 20.

SECTION THROUGH MERELAKE HILL, STAFFORDSHIRE.

Lower Mottled Sandstone. Conglomerate beds.

Nottinghamshire. — Proceeding eastward we lose all trace of this subdivision. At Leek, the Potteries, Cheadle, Alton, Ashbourne, and Derby, we find the conglomerates reposing directly on the Palæozoic rocks, and a person acquainted with the Trias only as it occurs in these localities, would probably infer that they lay at the base of the formation. It is therefore with some degree of surprise when, after an interval of about 30 miles, we recognize in the soft, bright red, and striped sandstone at the village of Dale, near Nottingham, the reappearance of the Lower Mottled Sandstone. The subdivision is not here greater than 25 feet in thickness, and from this point forms a constant, though variable, band at the base of the New Red Sandstone as it stretches northward into Yorkshire.

This subdivision is very finely exemplified in several sections from Lenton to Bramcote ; at the former place, in quarries and natural cliffs overlooking the alluvial plain of the Trent, and at the latter along the slopes of a range of hills, which are capped by the beds of the conglomerate subdivision. In these localities the beds are essentially the same as in other places already described, presenting the usual orange, or bright red, tinge streaked or blotched with white, combined with softness of grain and absence of pebbles. A little farther north, however, at Basford a few small angular fragments of green slates and grits occur, an exceptional case, but one to be expected in a series of sandy strata covering an area of about 300 square miles. The pebbles are small, and differ from those of the Conglomerate beds, to which the subdivision in question presents a strong contrast in general appearance.

The most remarkable section is that of the "Himlack Stone" at Stapleford Hill. Presenting at a distance the appearance of an old sea-stack, it is, as it seems to me, a very interesting relic of marine denu-

Fig. 21.

"HIMLACK STONE," NEAR NOTTINGHAM.

dation. It stands on a knoll separated from its contemporaneous beds of Bramcote Hill by a rather deep valley, and by a less space from Stapleford Hill. Being but 10 feet in diameter and 20 feet in height

it is remarkable that it should have resisted the destructive action of atmospheric agents since the period of its emergence. But an equally interesting circumstance is that the portion which we may call the capital of the column is formed of the Conglomerate beds, and the shaft of Lower Mottled Sandstone ; the column is, itself, only a disconnected portion of the escarpment of Stapleford Hill. The point of junction of the two sub-formations is shown in the accompanying sketch, where the harder stratum of calcareous grit with pebbles projects beyond the soft red sandstone.

I commend the Himlack Stone, a name possibly of Celtic origin, to the consideration of those geologists who deny to the former agency of the sea any share in sculpturing the features of the English landscape. That the Himlack Stone is an old sea-stack seems to me perfectly clear. It is to the sea-coast we should point in order to find similar examples; and they are not uncommon amongst similar red sandstones of Devonian or Carboniferous age on the raised terrace of the "25-feet beach" which fringes the Scottish coast.

In this locality the Lower Mottled Sandstone is about 80 feet in thickness, but farther towards Nottingham it must be fully 100 feet, or more. The base may be seen resting on Coal-measures in a lane near Bramcote leading from the Himlack Stone.

The Lower Mottled Sandstone forms a continuous though narrow band northwards into Yorkshire by Mansfield and Worksop, where it has been described by Mr. Aveline of the Geological Survey.* It occupies the slopes leading up to the "forest lands," and along the banks of the Leen near Basford, at Bulwell Spring, Hucknall, Newstead Abbey, and "Robin Hood's Stable," sections may be observed. It is also worked for moulding sand, both at Worksop and Mansfield, for which purpose it is very well adapted, being tenaceous, free from pebbles and from earthy matters.

Unconformity of the Trias and Permian Beds.—At Tickhill, South of Doncaster, the New Red Sandstone, represented by its basement beds, rests on the upper magnesian limestone, which is there laid open in extensive quarries, and which was long since described by Professor Sedgwick; but it has been shown by Mr. Aveline that the upper limestone when traced further south disappears beneath the New Red Sandstone near Worksop, which comes down upon the beds of marl and sandstone which are interposed between lower and upper limestones. At Mansfield, the New Red Sandstone rests in some places on the lower limestone, and at Nottingham it passes over the whole of the Permian series, and reposes on Carboniferous rocks. It is, therefore, clear, that in this district, as well as in those of the central and western counties, there is a decided discordance between the Triassic and Permian rocks, varying in intensity according to position, but always producing a difference in the amount of dip of the beds even where the direction of the strike happens to be the same.

Variegation and Mottling of the Sandstone.—On the causes of the streaked and mottled aspects of the sandstones of this and other formations Mr. George Maw has recently published some observations founded on chemical analyses of differently coloured portions of the same rock.† From these experiments he considers that nearly in all cases, red and brownish-red colours, such as those which

* "Geology of Parts of Notts and Derbyshire," and "Geology of Parts of Notts, Yorkshire, and Derbyshire."—Mem. Geol. Survey.

† "On the Disposition of Iron in Variegated Strata," Quart. Journ. Geol. Soc., vol. xxiv., p. 355.

the New Red Sandstone and Permian beds generally present, are due to the presence of iron in the state of anhydrous sesquioxide; that yellow colours, such as the Upper Mottled Sandstone and Lower Keuper Sandstone present in some places, are due to the presence of iron in the state of hydrous sesquioxide; while blueish tints are due to carbonate of protoxide of iron. (?)

In the case of mottled and streaked red sandstones, he believes, that the blotching is due to the discoloration of the rock through the abstraction of some of the sesquioxide of iron; but that there is no essential chemical difference between the red and colourless bands, or blotches, except that the latter portions become hydrous. In all these shades of colour the iron principally occurs as sesquioxide; and the slight differences in the proportions of protoxide and sesquioxide are so irregular that they appear unconnected with the variegation.*

CHAPTER VI.

The Conglomerate Subdivision.

Bridgenorth District.

I shall commence the description of the third subdivision at the typical district of Bridgenorth, and follow the course pursued when treating of the lowest member of the series.

Breccia, Old Shingle Beach.—As already remarked the basement bed at Bridgenorth consists of breccia, generally, though not always highly calcareous, in which state it is exceedingly hard, producing the fine ridges of Apley Terrace, Pendlestone Rock, Abbots' Castle Hill,

Fig. 22.

Pendlestone Rock.

and Kinver Edge. From this it may be traced, though in a less consolidated form, southwards by Blakeshill Camp and Horseley Bank, till it terminates along a line of fault against the Old Red Sandstone at Cornhill. The escarpment again reappears further south to the west of Kidderminster, and after trending in a nearly semicircular form to the south, south-west, and west, terminates on the banks of the Severn south of Bewdley. The thickness of the breccia varies with its direction, diminishing and gradually disappearing towards the north and east,

* The question is beset with difficulty, and further experiments appear to be required to confirm those conclusions.

while it increases to a maximum of 60 or 80 feet towards Kidderminster. When not cemented into a solid mass by carbonate of lime, the breccia might easily be mistaken for Drift, as it is then merely a loose angular gravel; in which state it occurs where crossed by the Stourbridge Road at Stourton. In this unconsolidated form it may be seen in some places along Kinver Edge and Abbots' Castle Hill. The following fragments of older rocks are there its principal components :—

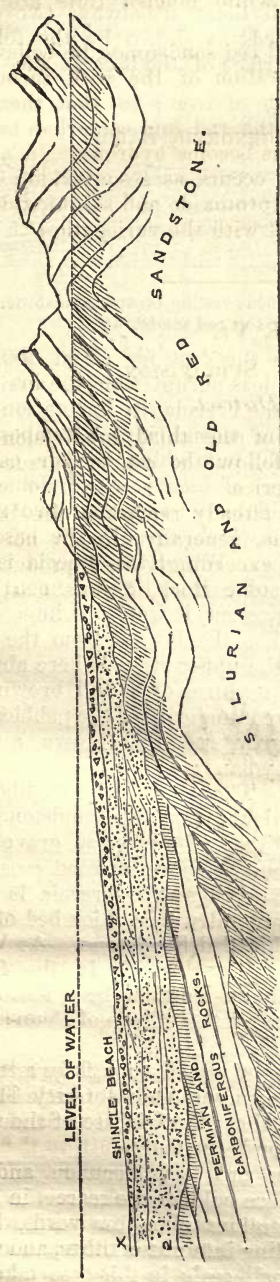
1. White quartz, generally rounded.
2. Blue and grey limestone, of which there are occasionally large lumps.
3. Indurated slate, fragments small, and sub-angular.
4. Grits of various colours and varieties.
5. Red argillaceous sandstone, small fragments (from the Old Red)?
6. Decomposed greenstone.
7. Jaspar (fragments small).
8. Bluish grey felspar.

At Horseley Bank and Habberley Edge, west of Kidderminster, the breccia is well exposed to view in the road sections. It is composed of irregularly-bedded brecciated conglomerate, sometimes degenerating into a loose gravel, in other places cemented into hard rock by carbonate of lime. The pebbles are for the most part from local or proximate sources, mixed with a few of the usual coloured quartzites; and the following were observed on a recent visit:—

1. Yellow quartzite (rounded).
2. Small pieces of white quartz.
3. Purple and white crinoidal limestone, crystalline and in large pieces (plentiful).
4. Green indurated slate (small, sub-angular).
5. Purple, very hard fine-grained grits.
6. Green fine-grained grits (scarce).
7. Fine-grained purple and speckled sandstones.

Fig. 23.

IDEAL SECTION TO ILLUSTRATE THE MODE OF FORMATION OF THE BRECCIA AT THE COMMENCEMENT OF THE CONGLOMERATE STAGE.



x. Breccia at base of Conglomerate series. *z.* Lower Mottled Sandstone filling up to a certain level the bottom of the old Palæozoic sea. Salopian and Welsh hills, land in part of the Bunter period.

As the greater proportion of the pebbles are angular it cannot be supposed that the parent rocks are situated at a great distance. Indeed the pebbles are such as may have been derived from the rocks

of the Carboniferous, Devonian, and Silurian districts adjoining. We may therefore suppose the breccia to have formed a gravel beach which swept round the flanks of the older hills of Wales and Shropshire. Its mode of formation I have endeavoured to represent in the ideal section (page 45.)

In the neighbourhood of Bridgenorth there are always two distinct ridges formed by the conglomerate beds as shown by the following section. Upon reaching the upper surface of the breccia the ground

Fig. 24.

SECTION OF EAST BRIDGENORTH, SALOP.

U.S. Upper soft red sandstone. C. Pebble beds resting on soft sandstone.
B. Breccia. L.S. Lower soft red sandstone.

is found to slope downwards towards the east for about 300 or 400 yards; when it again rises in a ridge less abrupt than the first. The sloping ground is the upper surface of the breccia, its inclination corresponding with the dip of the beds. The second ridge is composed of a sandstone containing scattered pebbles, but which farther east and north becomes occasionally a thick mass of quartzose conglomerate in the fullest sense of the term. Intermediate between the two ridges a local bed of soft red sandstone occurs which occupies the base of the upper ridge and the intermediate valley. Where the breccia is absent the beds of the second ridge become, of course, the basement of the Conglomerate subdivision; as, even if present, it would be impossible to separate this stratum which here overlies the breccia from the underlying subdivision. The sandstone of the upper ridge is here about 300 feet thick.* It is of a rather coarse texture, of a dull brownish-red colour, and irregularly bedded. The great majority of the pebbles which are scattered throughout consist of grey, red, and brown quartzite, together with fragments of black Lydian stone, which are always associated with the quartzite pebbles. Though in this neighbourhood the pebbles are but few, there is no doubt that this sandstone passes locally into a rock formed almost entirely of quartzose gravel. Nor have we far to seek for an illustration. Where the road crosses the ridge between Stewponey Inn and Stourbridge the breccia is absent, and the conglomerate subdivision is represented by a thick bed of gravel which is seen reposing on the Lower Mottled Sandstone. At Wolverhampton, this subdivision occurs almost exclusively in the form of quartzose conglomerate, resting directly on Permian beds, and forming the ridge which stretches from the town to the village of Penn; at this village it may be advantageously studied.

One of the most remarkable features of the district is presented by the abrupt termination of the ridge known as Abbots' Castle Hill near Claverley. This escarpment, which is the physical base of the Conglomerate beds, is a continuation of Kinver Edge.

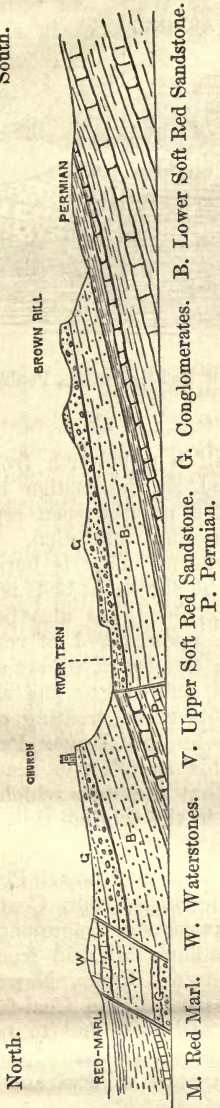
Variations in lithological character are both common and rapid wherever these beds occur. In one place pebbles are scarce, in another not far distant very plentiful. In sections of a few yards, beds of gravel and sand are often seen dovetailing into one another, and we may well suppose that what occurs on a small scale in this case takes place also on a larger.

* Horizontal Section 2, sheet 54.

The Pebble beds are laid open for a length of 100 yards in the road on the opposite side of the Stour valley, and are worthy of examination on account of the great size of the pebbles of which they are composed. The greater proportion are composed of liver-coloured quartzite, but specimens of Carboniferous limestone filled with encrinite stems are frequent, as are also black porcelain stone.

Fig. 25.

SECTION THROUGH MARKET DRAYTON, SALOP.



Newport and Market Drayton.—The beds of this subdivision are spread over a large area west and north of Newport in Shropshire, and consist of reddish-brown sandstone, traversed by current-bedding, and with pebbles interspersed in variable quantities. At Chetwynd Park the quartzose conglomerate, which here forms the base of the Trias, rises into a picturesque escarpment terminated at the north along the line of a downthrow fault. Here, as in the district between Bridgenorth and Wolverhampton, we generally find that the sudden termination of a ridge of conglomerate, or breccia, indicates the presence of a line of fracture and dislocation.

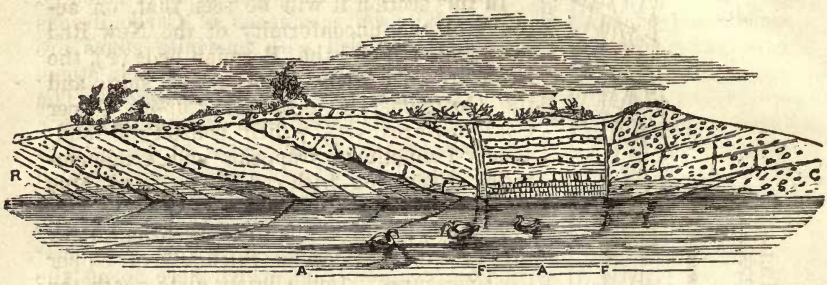
The town of Market Drayton stands on a platform of hard pebbly sandstone of this subdivision, surmounting the softer beds of the Lower Mottled Sandstone. On crossing the valley of the Tern towards the south, we again find the Pebble beds gradually rising towards their outcrop along the crest of Brown Hill, and dipping with the slope of the ground in the direction of the Tern valley. It is therefore clear that there is a fault in this valley, repeating the conglomerate and underlying beds on the south. This fault is shown in the adjoined section, from which the general structure and succession of the beds in this part of the country will be understood (fig. 25.)

In the canal west of Cheswardine a highly interesting section is exhibited. Walking from Stoney Ford southwards, we have an opportunity of observing the marls and sandstones of the Permian beds for a distance of more than a mile, till they are terminated by a fault which throws in the conglomeratic sandstone of the New Red series.* A sketch of this part of the section is here presented.

* At a point in the centre of the anticlinal, at a distance of 300 yards from the New Red Sandstone fault, a locality appears to be offered where a coal-shaft might be sunk with the expectation of reaching coal at a less depth than 1,000 feet. As in walking from Stoneyford we are continually passing into lower beds, we may suppose that at this point the beds are not very far from the base of the Permian. If we allow an additional 200 feet as the depth of the Coal-measures below the canal, this added to 300 feet (the thickness passed over in the distance to Stoneyford), we shall have 500 feet for the whole thickness of the Permian, about equal to its greatest amount along the borders of the South Stafford Coal-field. And, on the supposition of an additional 600 feet of Upper Coal-measures, the total depth to productive Coal-measures at this point will be 200 + 600 = 800 feet.

Fig. 26.

CANAL SECTION.—CHESWARDINE.



A. A. Permian Sandstones and Marls. C. New Red Sandstone, Pebble beds.
F. F. Faults.

Close to the Whitmore Road, at a point half a mile north from the Loggerheads Inn, a quarry has been opened, at the further end of which the Conglomerate beds of the New Red may be seen reposing upon the red and purple sandstones of the Permian formation. There is scarcely room for doubt that a case of unconformity is here presented, not only because the angle of dip of the subjacent beds is much greater than that of the strata which rest upon them, but also because a little farther north the conglomerate rests upon a bed of red marl which underlies the sandstone in the quarry; the result of an unconformable overlap. The sketch of the section referred to has already been given in a former page (fig. 5, page 25), when treating on the question of the unconformity of the Triassic and Lower Permian formations of the Midland Counties. To this sketch the reader is referred; and it is only necessary to add, that the lines which here mark the beds of the Permian Sandstone are in the original thin seams of marl.

That the large area of the Bunter Sandstone and Lower Permian formations, lying to the south of the North Staffordshire Coal-field, may be regarded as a reservoir of coal and ironstone, the upper beds of which are at no very great depth, may be fairly inferred from the direction of the dip of the measures at Longton, Stoke, Newcastle, and Silverdale. The general dip over this part of the Coal-field is southward; but the great obstacle to mining will be found to be the series of upper unproductive Coal-measures, not less than 1,000 feet in thickness, which overlies the first workable seam of coal and ironstone.

Quartzose conglomerates rest unconformably on Permian marls and sandstones between Whitmore and Stone, forming the picturesque high-grounds which rise west and south of Trentham Hall. From the north of Stone to the south of the Potteries there occurs a basin, occupied by Permian strata and Upper Coal-measures. It is bounded on the east and west by ridges of the New Red Conglomerate, and the southern extremity is terminated by a fault which throws down the Lower Keuper Sandstone against the Permian rocks. As the conglomerates which flank the basin dip from it on either side, an anti-clinal is produced, allowing the Permian beds, which generally dip to the westward, to occupy the basin. In the following section, drawn through Trentham Lake, if we

in imagination join the quartzose conglomerate across the intermediate space, it will be found to form an arch which rests on buttresses formed by Permian rocks and Coal-measures (fig. 27).

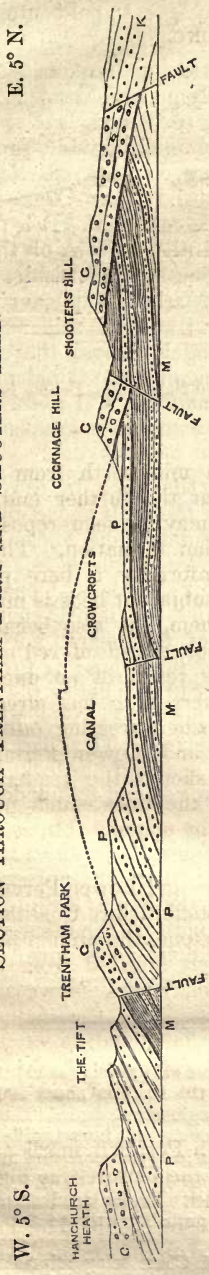


Fig. 27.
Section through Trentham Park and Shooters Hill.

In this section it will be seen that, on account of the unconformity of the New Red Sandstone (c) and the Permian beds (p), the latter are over-lapped on the east side; and the Conglomerate beds rest upon Upper Coal-measures (m), which consist of sandstones (sometimes trappean and conglomeratic) alternating with red, purple, and blue marls.

At Hanchurch, the fault of Trentham Park throws up a considerable thickness of Upper Coal-measures. Immediately underneath the shales, sandstones, and thin coal-seams, through which the new road is cut, there comes a thick bed of red marl, the same as that which is so largely employed in the manufacture of tiles at Upper Harts Hill near Stoke. These Upper Coal-measures have, as yet, scarcely been disturbed in search of mineral fuel.

West and north of Stone, the Pebble beds occupy the highest grounds in the neighbourhood, rising in conical shaped hills, not unlike artificial tumuli, or extending into lengthened elevations, the sides of which are steep, and worn into a series of undulating ridges and furrows, not unlike the swell of the sea after a storm. This form of ground is very characteristic of the Conglomerate beds all over the country when beds of gravel predominate. At Fir Clump these beds attain an elevation of 560 feet.* A promontory of conglomerate stretches northwards to the east of the Potteries, between the northern extremity of which, and the tongue of New Red Sandstone which extends southwards from Leek, a space of but three miles intervenes; and thus the coal-field is almost separated into two portions of unequal economic value, the most productive being situated on the west side. The unconformity of the New Red to the Permian rocks is abundantly proved in this district; for while the latter is probably accidentally conformable to the Coal-measures, the New Red Sandstone rests indifferently on beds high up in the Permian series, and low down in the Carboniferous. Thus, as far as we have seen, there is generally a greater break between the formations which form respectively

* See Horizontal Section of the Geol. Survey, No. 1, sheet 57.

the limiting deposits of the Palœozoic and Mesazoic periods, than between those which belong to the same great palœontological series.*

Cannock Chase.—The conglomerates of Stone are connected with those of Cannock Chase by a long strip of hilly ground, formed chiefly of the same beds, which, being bounded on the east and west sides by faults occasioning a downthrow of the Red Marl on either side, produces a ridge of some elevation above the surrounding country; particularly that side of it which stretches away westward. Near Cannock the more westerly fault joins that which bounds the coal-field. It is, therefore, one of much interest, as it proves the identity in time of the disturbances which upheaved the North and South Staffordshire coal-fields. As the former fault affects the Red Marl, the upheaval must have occurred subsequently to its formation; and of this we have additional evidence in the neighbourhood of Rugely, where the eastern boundary fault brings down the Red Marl itself against the Conglomerate. Phenomena of a similar kind are observable at Church Lawton north of the Potteries, where the Red Marl is thrown down against Coal-measures.

That portion of Cannock Chase bounded on the north by the Trent, on the east by the coalfield, and on the west by the fault above referred to, is composed of strata of the Conglomerate subdivision, consisting of highly pebbly sandstone, or partially unconsolidated quartzose gravel. The physical features are highly characteristic of the rocks. Considered on a large scale, the Chase forms a table land, the upper surface of which is nearly level, being, in fact, the top of the nearly horizontal beds of the Conglomerate subdivision.† This table land is furrowed into numerous narrow valleys, worn to 100 or 150 feet below the upper surface of the plain, and presenting along the flanks that peculiar wave-like aspect to which we have already referred. The Chase is in its naturally wild state, covered with heather, sparingly bedecked with firs and natural birch, and over its whole extent roe and fallow deer are still free to roam.

Along the banks of the brook, extending from Hednesford Pool to Lower Cliff, numerous springs gush forth. It therefore appears probable that along its bed, as far north as Baland's Pool, Coal-measures are near the surface. It is also probable that most of the other valleys between this part of the brook and the coal-field are worn down nearly to the base of the New Red Sandstone, so that should productive Coal-

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* At Moddeshall an enterprising farmer was at the time of my visit (1854) engaged in sinking a shaft in search of coal. The position of the shaft is about 100 yards from the lower boundary of the New Red Sandstone conglomerate beds. The strata are Upper Coal-measures, consisting of bluish-grey sandstone interstratified with shale and two thin seams of coal. They are very similar in appearance, and no doubt identical in position with the Upper Coal-measures shown in the railway cutting at Newcastle-under-Lyne, with the thickness of which, down to the productive Coal-measures, we are not at present acquainted, but they probably average 300 yards. The attempt has since been abandoned.

† The cause of the flat tabulated surface of Cannock Chase being coincident with the top of the Conglomerate sub-division (considered as one bed) arises from the fact of the former superposition of the upper red and mottled sandstone, which being of so soft and yielding a nature as compared with the beds on which it rested, has been swept away along with the superincumbent formations, thus leaving the upper surface of the conglomerate as the upper surface of the Chase, "a plain of marine "denudation."

measures prove to underlie Cannock Chase, of which there can scarcely be a doubt, these valleys offer great facilities for coal shafts.*

Between Saredon Brook near Cannock and Wolverhampton, a district extends, the geological structure of which, owing to the Drift and the paucity of sections, was for some time very difficult of elucidation. Several parallel ridges occur, ranging north and south, which, when sections are exposed, are found to consist of quartzose conglomerate, quarries in which have been opened at Bushbury and Essington Mill. Some of the ridges, however, as Cheslyn Hay and Little Saredon afford no sections, but on account of their similarity in form to the others, and the quantity of quartzose gravel spread over their surfaces, we are led to the conclusion that they are also composed of conglomerate. Each of these ridges presents a flat gently sloping side to the west, and another more rounded and abrupt, to the east; features which are usually found to characterize respectively the upper surfaces and terminal edges of New Red Sandstone beds. Moreover, at Bushbury Hill, on the east side from one of these ridges, a quarry has been opened in Permian Sandstone. Permian marl, similarly situated below gravel ridges, occurs at Shareshill and Great Saredon, also at Essington Wood and Wyrley Bank. Such are the data from which we have to draw conclusions regarding the geological structure of the district. The only satisfactory explanation of this structure seems to be on the hypothesis of several north and south faults, which bring up Permian strata in a succession of narrow bands, the downthrows of all being on the east side with the exception of the two lateral faults, the downthrows of which are on the west. At Bushbury one of these last brings the Red Marl and Lower Keuper Sandstone in contact with the Conglomerate beds. The marl and underlying sandstone may be seen in a wood north of the village, where they dip towards the conglomerate ridge to the eastward. (See Hor. Section, sheet 45.)

Colwich.—In this neighbourhood,—where nearly 20 years ago I first made acquaintance with the New Red Sandstone, there are many excellent

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* Mr. Jukes* gives the following section of a boring undertaken by Lord Lichfield near the pool of the rolling mill S. of Hagley Park, Rugeley, from which it would appear that the conglomerate sub-division is here at least 270 feet thick. Below this there are certain beds nearly 150 feet thick, which would seem to be Permian, from which we may suppose that this formation extends uninterruptedly to the borders of the North Staffordshire Coal-field. The following is the section referred to :—

Boring—Cannock Chase.

	Feet.
1. Sandstone and gravel - - - -	269
2. Red sandstone and beds of marl - - -	143
3. Black and red marls with ironstone - - -	133
4. Coal - - - - - -	1
5. Red, white, and brown rocks, with red or white marls and "blue binds" - - - -	66
	612

No. 1 is evidently New Red Sandstone; No. 2 probably Permian; the rest Coal-measures. The 1 ft. coal here reached is supposed to be underneath the 15th seam, below which, at Brereton Colliery, "Red Measures" were found. In this district the dip of the Coal-measures is toward the south-east; that of the New Red Sandstone being in the opposite direction.

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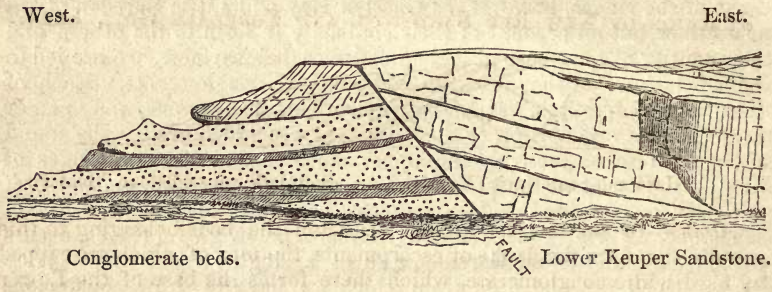
* See Horizontal Section, sheet No. 23.

sections, especially along the line of the Trent Valley Railway. The Conglomerate beds are well laid open at the entrance to the tunnel at Colwich Park, and in the cutting at the opposite side of the Park, of which a sketch is here given.

Fig. 28.

SECTION NEAR COLWICH, STAFFORDSHIRE.



The above section is exposed to view in the Trent Valley Railway near Colwich. It shows the white freestone at the base of the Keuper formation dropped down by a fault against quartzose conglomerates of the subordinate series. This is one arm of a trough fault, for on walking along the line for a 150 yards eastward we find the other arm bringing up the Conglomerate beds again to the surface. It will be seen on reference to the map that these faults, which unite a short distance north of the railway, throw back the white freestones of the Lower Keuper Sandstone to the opposite side of the Trent, a distance of half a mile to the south of their ordinary boundary, for we find them in a quarry on the south side of the Stafford road, and of a character similar to the beds in the railway cutting.

Cheadle.—Returning into North Staffordshire we find the Conglomerate beds sweeping in a picturesque semi-circle round the Coal-basin of Cheadle, in the centre of which stands an outlier of pebbly sandstone of the same sub-division, on which the town is built. The thickness of the sub-division here is more than 300 feet. The strata are also greatly faulted, and at Upper Tean, in proximity to a fault visible in the road, the pebbles are indented and crushed ; a phenomenon which will be more fully noticed hereafter. At the hamlet of Totmanslow the cutting in the turnpike road affords a good section in the Pebble beds, which are dislocated by the same fault which farther west brings them in contact with the Keuper Marl.

Leek.—The tongue of New Red Conglomerate stretching south to a distance of four miles from Leek occupies a depression in the Carboniferous strata, which rise into higher ground on both sides.* The beds all belong to the Conglomerate sub-division, and are composed of coarse soft sandstone containing thickly scattered quartz pebbles. It is surprising that not one pebble in a hundred can be referred to the Carboniferous rocks. An interesting case of unconformity is exhibited in a lane section near Moss Lee Mill, in which the junction of the New Red Sandstone and Yoredale Grit is shown. It is evident from the sketch below (fig. 29), which is taken from a woodcut by Mr. A. H. Green,† that

* See Hor. Sec., sheet 42.

† "Geology of Stockport, Macclesfield, &c."—Mem. Geol. Survey, p. 62.

the elevation which affected the conglomerate has here diminished the inclination of the grit, which previously had been vertical, or nearly so. Another small outlier occurs at Endon, formed of similar rock. The character of the rocks in this neighbourhood has been very truthfully described by Mr. Wardle in his "Geology of Leek."

Fig. 29.

JUNCTION OF NEW RED SANDSTONE AND YOREDALE GRIT, LEEK.

Hard and coarse grit (Yoredale). Soft dark red sandstone (Bunter).

Alton.—In the neighbourhood of Alton the beds belonging to this sub-division form the flanks of escarpments, the tops of which are capped by hard white conglomerate, which there forms the base of the Lower Keuper Sandstone. The higher beds are very soft, and contain but few pebbles; the lower are of a firmer character. At Alton a good section in these two sub-divisions of the Trias is exhibited in the road-cutting between the village and the railway station. This district will be more fully described in a future page.

At Ashbourn the predominating colour is white or yellow, characterizing both the Lower Keuper Sandstone and Conglomerate beds of the Bunter Sandstone, hence positive and relative degrees of hardness are the only guides in tracing boundaries between the two sub-divisions. This similarity only extends over a very small area; for, after crossing the Dove to the eastward, the conglomerate at the base of the Keuper series disappears, and the sub-formation is introduced by a bed of marl. A fine section in the Bunter Sandstone is open in a road south of Ashbourn, showing a thickness of 120 feet of beds, which consist of soft yellow and light red sandstone with scattered pebbles and thin partings of marl. In a brick-yard half a mile from the town on the Matlock road these soft yellow beds were found reposing on highly inclined strata of Carboniferous Limestone Shale. The section was unfortunately small and imperfect.

Around Derby, the Conglomerate beds occupy high ground, climbing along the upper surfaces of the ridges of Carboniferous rocks till they attain elevations nearly equal to those of the Millstone Grit. As regards superficial extent they are very inconstant, being often entirely absent below the Keuper series, as at Muggerton and Kirk Langley; this I consider to be due to the irregularity of the old sea bed. The best sections occur at Bradley Wood, Brailsford, Morley Dame's Hill, Dale, Sandiacre, and Bramcote.

Nottingham.—The greater part of Nottingham is built upon a coarse white sandstone, containing numerous scattered pebbles of quartzite, black chert, and other rocks. False-bedding is prevalent, and, as a whole, the beds of this sub-division are of a harder texture than those of the Lower Mottled Sandstone, which consequently occupies the valleys or flanks of the ridges. At the same time the Conglomerate sandstone is unsuited for building purposes, owing to its softness, and the number of pebbles it contains; but for the purposes of water supply, and as a site for building purposes, it is admirably fitted.

The Conglomerate beds attain a thickness of at least 300 feet, and there is a gradual declination of the surface (corresponding to the dip of the strata), towards the south-east, in which direction they are finally concealed beneath the Lower Keuper Sandstone and Red Marl.

The old fortress of Nottingham Castle stands, or rather stood, on the summit of a lofty cliff of sandstone belonging to the Conglomerate subdivision. Its southern face is vertical, and the battlements command an extensive view, bounded by the rugged outline of the hills of Charnwood Forest. The rock itself forms a portion of the cliff which bounds the alluvial plain of the Trent, and may be traced from New Lenton to Sneinton. Though the river doubtless once washed its base, the channel is now distant therefrom nearly a mile.*

Throughout its range, from Newstead Abbey to Nottingham, the Bunter Sandstone is underlaid by a band of red marl belonging to the Permian formation. Now, in consequence of this arrangement of the strata, a large quantity of water makes its escape in the form of springs along the western margin of the Bunter Sandstone in the valley of the Leen, one of the most copious of which is the Bulwell spring, which yields a constant flow, probably not far short of one million of gallons per day. That very large quantities of water are locked up in the sandstone rock under the forest lands north of Nottingham may be inferred from the fact that the rock itself is of an extremely soft and porous texture, and everywhere exposed at the surface, or only concealed by a thin coating of gravel, so that the rain percolates downwards almost as quickly as it falls. Another indication is the almost entire absence of brooks and ditches, and the outburst of the springs such as those at the fountain head of the Dover Beck.

The Pebble beds form a ridge of high ground extending from Beeston field to Stapleton hill. Along this line their boundary with the Coal-measures is necessarily a fault, as the Lower Mottled Sandstone is concealed. For a similar reason the boundary from Stanton to Dale is also a fault.

At Stapleton hill there was once a mine of copper ore. The rock is there highly mineralized, but I could find no specimens of vein stone containing ore. The works have evidently been abandoned for a long time.

Sherwood Forest.—The Pebble beds form a broad band of country sketching northward to the valley of the Humber by Sherwood Forest, Retford, Blyth, and Spittle hill, east of Tickhill. All along this tract the beds rest on the Lower Mottled Sandstone, and have a gentle dip to the eastward. The country occupied by this formation consists for the most part of rounded hills and dells, covered by sand and gravel, the disintegrated materials of the formation itself. Mr. Aveline, who describes these beds in this district, says, "Owing to the nature of this "rock there are few sections exposed, taking into account the extent "of country it covers. This arises from its soft nature, so that, instead "of standing out sharply like the harder rocks, it is worn into rounded

* Mr. Aveline, F.G.S., in his description of these beds, says:—"The rock is not "so hard but that it can be easily worked, and such is its massive consolidation, and "so few are the lines of bedding or joints, that it can be hollowed in large square "chambered caverns without requiring any artificial support for the roof. Advan-"tage has been taken of this peculiar structure and the dryness of the rock to make "use of it. Along the face of the cliffs chambers of various sizes have been hollowed. "Several small inhabited caves of this kind are to be seen at Sneinton, known as the "rock houses, and on the south side of the part there are 'the rock holes,' excava-"tions so ancient that their date is unknown."—"Geology of the Country around "Nottingham," p. 19.

" hills and buried in its own débris. Being useless for most purposes " there are also few artificial sections."* The rock, however, may be observed on the south side of Robin Hood's hill, Newstead Abbey, on the hill side east of Mansfield, at Sparking hill, and in the Worksop and Retford road, and in the cuttings of the railway west of Retford.

The general character of the sub-division throughout the district is that of a partially consolidated conglomerate, or pebbly sandstone, the pebbles consisting of, for the most part, quartz-rock of red, purple, yellow, and greenish colours, all well rounded and waterworn, with occasional fragments of rocks derived from other formations, such as purple sandstone, green indurated grit, green slate in small fragments, white quartz, jasper, Lydian stone, Carboniferous encrinital limestone, and chert. Some of the quartzite pebbles are occasionally found from four to five inches in diameter. The source and origin of these peculiar quartzites will be discussed in a future page.†

Shrewsbury to Holt, Cheshire.—Retracing our steps into Shropshire we shall follow the course of these strata in a rapid manner from Shrewsbury northward. As compared with their representatives at Nottingham and Derby, we shall find the beds of this sub-division along the western borders of Cheshire more fully developed, less pebbly, of a firmer texture, and often adapted to building purposes.

In the bank of the Severn, at Longnor Hall, a quarry has been opened in tolerably hard reddish-brown sandstone, which probably belongs to the Conglomerate series, though no pebbles could be found in it. It is close to a fault by which it is thrown down against Coal-measures.

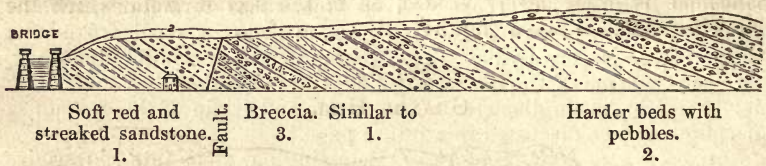
Owing to the depth of the Drift deposits from Shrewsbury to Chester, comparatively few sections are exposed to view. Quartzose conglomerate occurs in a lane faulted against the Lower Mottled Sandstone, close to the Welshpool Road, about four miles East of Alderbury. Nearer the village, these beds may be seen resting on the Lower Mottled Sandstone, and close to the fault which brings them into contact with the calcareous breccia of the Permian formation. Sections occur also at Woolstone, Knockin, and Kinnersley. After leaving these, we do not meet with sandstone *in situ* till we arrive at the banks of the Dee at Bangor. Here, at "The Gripes," a quarry has been opened in reddish-purple sandstone, containing scattered pebbles and a bed of marl. The rock is probably near the base of the sub-division. At Holt a splendid section is opened out on both banks of the Dee. The rock consists of several alternations of bright red, soft, with coarser brown and purple sandstone, containing pebbles scattered throughout. The lowest bed seen occupies the centre of the section, being brought up by a fault, which may be observed in the garden of a cottage, a few yards south from the bridge on the east bank. This fault crosses the river, and traverses the cliff upon which Holt Castle is built. The lowest bed referred to is a breccia, of a dark purple colour, passing occasionally into yellow. It is visible on the same bank farther North near Aldford, in the valley east of Little Mollington, near Chester, and in a quarry south of Stretton Hall. This breccia is so similar in lithological character and position to that which forms the base of the Conglomerate series at Bridgenorth, that I think it highly probable they are identical in stratigraphical position. The principal difference (and it is unimportant) consists in the smallness of the pebbles at Holt, but they resemble those of Bridgenorth in composition, consisting of chert, white quartz,

* "Geology of Parts of Nottingham, &c."—Mem. Geol. Survey, p. 13.
† Page 59.

and various kinds of grits. At Holt the breccia is also succeeded by soft red streaked sandstone, which separates it from pebbly sandstone, and similar to that which occupies a parallel position at Bridgenorth. The similarity of the series in both places is worthy of observation. The following section, taken from the right bank of the river, will bear comparison with that already given in page 46.

Fig. 30.

Section along the Banks of the Dee at Holt, Cheshire.



Chester.—The conglomerate sandstones, which occupy so large an area of the country extending south, east, and north from Chester, will not require a detailed description, as they preserve a uniform character over the whole area. They may be described as rather coarse, brownish-red sandstones, streaked occasionally with yellow, and having pebbles scattered at intervals through the mass. They are extensively quarried between Holt and Chester, as also at Handley, Waverton station, Dunham, and Backford. At Chester numerous sections are exposed along the banks of the Dee, and in the railway and canal cuttings. Though extensively employed as a building stone, the crumbling condition of the cathedral, the churches, and other buildings in the city, proves that the sandstones of this sub-division are not sufficiently durable for edifices which are intended to last for centuries; for such purposes the freestones of the Lower Keuper Sandstone are better adapted.

In this neighbourhood the Conglomerate beds form gently sloping ridges or bosses, rising above the surrounding flats, which are occupied by the softer sandstones of the adjacent sub-divisions, and generally deeply covered with Drift clay.

Wirral.—Similar features are produced by these beds in the district between the estuaries of the Mersey and Dee, and the ridges have an approximately North and South strike.* The rock is quarried at Shotwick, Neston, Thornton, Bromborough, West Kirby, Birkenhead, Walton, Tranmere, Kirkdale, Æverton, Knotty Ash, and Wavertree. Pebbles are seldom abundant, but may always be found where a large section is exposed. The sandstone of this sub-division is, however, so distinct in its characters from that of either of the under, or overlying sub-divisions, that the presence of pebbles is not always necessary to its identification.

I have already referred to the coast sections at Barton Point and Eastham Ferry, where the Conglomerate beds are seen reposing upon the Lower Mottled Sandstone. At Barton the thickness of these beds was found to exceed 400 feet. From Eastham Pier to Rice Wood, a distance of nearly two miles, a continuous section is presented, the beds

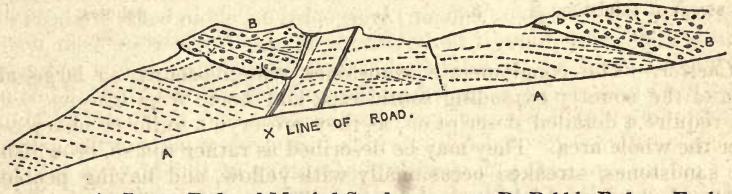
* A section across this district was presented before the British Association at Liverpool, and has since been reproduced by Mr. J. H. Morton in the "Transactions "of the Lancashire Natural History Society, 1856." More recently, the structure of the Wirral peninsula and adjoining portions of Lancashire has been illustrated by a Horizontal Section levelled from Little Eye, in the estuary of the Dee, to Horwich Moor, near Wigan, crossing Birkenhead, Liverpool, Knowsley, and the Wigan Coal-field.—(Sheet 68 of Hor. Sections of the Geological Survey), 1865.

dip north-west at an average of 2°, and, though no faults occur, the rock is traversed by numerous joints, the direction of which is north and south, consequently parallel to the lines of disturbance of the surrounding country. The thickness of the sub-division was here found to be 350 feet.

At West Kirby the Conglomerate beds form an escarpment, rising about 200 feet above the sea. The beds which contain pebbles are very hard, and are separated by two interstratifications of soft red sandstone. At the line of junction the surface of the Lower Mottled Sandstone is often deeply eroded, as in the section from which the following sketch is taken (fig. 31).

Fig. 31.

GRANGE HILL.

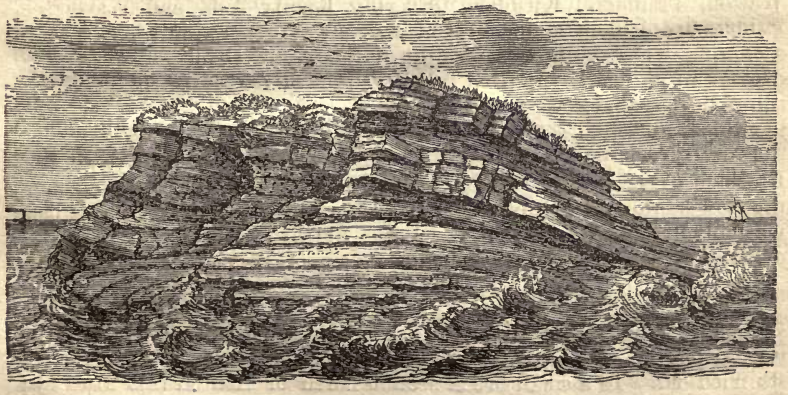


A. Lower Red and Mottled Sandstone. B. Pebble Beds × Fault.

At Hilbre Point, near Hoylake, a spur, or reef, of sandstone belonging to the Conglomerate series, strikes northward into the sea, with an easterly dip. It is highly probable that the eastern edge is a line of fault, perhaps a continuation of that represented in the above woodcut (fig. 31).

A second reef formed of the same beds, also dipping to the north-east, runs from Hilbre Island in a south-easterly direction for a distance of two miles. At low water the whole reef is uncovered, but at full tide, the highest points form three little islands. It is highly probable that this reef is bounded on the east by a line of fault, as the beds dip towards the Lower Mottled Sandstone of the opposite coast. In sinking for coal beneath the New Red Sandstone, the ground east of this inferred north and south fault would afford an eligible site, as the beds which there reach the surface are near the base of the formation.

Fig. 32.



MIDDLE ISLAND, ESTUARY OF THE DEE
(*showing position of the breccia bed*).

At Middle Island a remarkable bed occurs in a position about the centre of the section. It consists of breccia composed of angular fragments of rocks, which are met with on the opposite coast of Wales. They are principally fragments of Coal-measure sandstone or Millstone Grit, white quartz and greenstone. Both under and above the breccia the pebbles which occur in the sandstone were found to be the usual coloured quartz (see fig, 32, page 57).

Liverpool district.—The beds of the Conglomerate sub-division here consist of reddish-brown pebbly sandstone, moderately hard and adapted for building purposes of ordinary character, for which they are largely wrought. Consequently numerous sections have been opened out in quarries both at Liverpool and also at Walton, Kirkdale, West Derby, as well as in the Manchester Railway cuttings near the eastern entrance to the tunnel, and at Roby.

All along the eastern side of Liverpool the Pebble beds are brought to the surface by a large fault, passing through Æverton from north to south. On the west side of this fault the country is low and comparatively level, being occupied by the soft beds of the Upper Mottled Sandstone and Keuper series. On the east side the harder Pebble beds rise into an elevated ridge, which commands a view of the greater part of the town, together with the estuary of the Mersey and the opposite coast of Cheshire. This fault where crossed by one of the horizontal sections of the Geological Survey has an estimated displacement of 1,500 feet.* The dip of the beds is eastward under the Upper Mottled Sandstone, which occupies a strip of depressed ground, deeply covered by Drift clay, but the Pebble beds are again brought to the surface by another fault, parallel to the last, and passing west of Wavertree. The rock may be seen at Hale, Woolton, West Derby, and Fazakerley. The dip is still east in the direction of the small coal-field of Croxteth Park, against which the Pebble beds, together with those of the Upper Mottled Sandstone, are faulted.

East of Croxteth, we find the Pebble beds spreading out over a large tract of country, and at Knowsley, faulted against the Carboniferous Rocks. The beds are shown in several sections, as at the Red Delf, and Windmill Quarries. At Knowsley Quarry the rock is very hard, and is traversed by planes of current-bedding, along which it is worked for flags and paving stones.

The coal districts of Prescot and St. Helens are separated by a promontory stretching northward into the Coal-measures, composed principally of the Conglomerate beds of the New Red Sandstone. They are finely laid open in several large quarries, and in the railway section west of Rainhill, where the beds dip steadily west at an inclination varying from 10° to 20°, and showing a thickness of not less than 500 feet. The promontory is bounded on both sides by large faults, and in its centre a shaft has been sunk which supplies St. Helens with good water. Indeed the Bunter Sandstone when favourably situated may be considered as an admirable reservoir capable of affording an almost unlimited supply of pure, though rather hard water, as will be shown in a future chapter.†

Along the southern boundary of the coal-field extending from Sutton to Haydoc, a band of Lower Mottled Sandstone forms the base of the New Red Sandstone ; but at Ashton-in-Makerfield and Edge Green the Conglomerate beds form the base, the lowest member having apparently thinned out. In a small brook section north of Ashton this immediate

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* Horizontal Section, sheet 68 (see "Explanation" thereto, p. 3). † Chap. xii.

superposition can be clearly determined, and the beds, which are everywhere of a similar character, may be observed in quarries at Ashton, Newton, and Winwick.

Manchester and Stockport District.—As already observed, the Conglomerate subdivision rests directly on the Permian and Carboniferous Rocks all along the southern skirts of the Lancashire Coal-field from Edge Green near Wigan to Manchester, and southward into Cheshire, the Lower Mottled Sandstone being absent. The rock has also been pierced in several places by coal-shafts, which have traversed the subjacent Permian beds down into the coal; as, for example, at Edge Green, Bedford, and Patricroft, as originally described by Mr. Binney.* All along this line of country there is a slight amount of discordance between the terminal beds of the mesozoic and palæozoic series.

The subdivision consists of reddish-brown sandstone, variable in hardness and texture, and containing rounded pebbles of quartzite which are only locally plentiful. It is not so well adapted for building purposes as in the neighbourhood of Liverpool, being generally softer and more liable to disintegration. The thickness seems to vary between 600 and 900 feet. The former estimate was obtained by myself from measurements made along the banks of the Mersey below Stockport, and the latter by Mr. Binney from the thickness as ascertained at Pendleton Colliery.† Very fine sections may be observed in the banks of the Irwell for several miles from Manchester upwards to Ringley, where the rock has been projected northward along the line of the Great Irwell-Valley fault, which has a downthrow at Clifton of 3,000 feet. Other sections are laid open at Stockport, where the base of the formation, in the form of a breccia, may be observed resting on red marls of Permian age; and again still farther south along Bramhall Brook near Poynton, and in Dean Brook near Bollington close to the "Red Rock Fault."‡

We have now followed the course of these beds over the district coming within the limits of this Memoir, and we shall leave them at the point where they disappear beneath the higher divisions of the Trias along the line of the Cheshire fault near Macclesfield. They again emerge near Talk-on-the-Hill in North Staffordshire, along the margin of the Coal-field, and near to the section in Merelake Hill previously described (see fig. 20, p. 42).

On the Source of the Quartzose Conglomerate.

In describing the middle subdivision of the Bunter Sandstone it will have been observed that in some places it occurs as conglomerate, in others, as a pebbly sandstone. In parts of Notts, Derbyshire, and Staffordshire, the subdivision is characteristically a partially consolidated quartzose gravel, and in these districts it is that the pebbles attain their largest size. If we draw a line from Worcester, which may be assumed as their southern limit, and carry it northward to the east of Nottingham through Leicestershire we have the actual limit of these gravel beds, while they may be traced northward through Sherwood Forest to the Humber. Westward, their limit *in the form of gravel beds* is the neighbourhood of Shrewsbury, for in the districts of

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* "On the Permian Beds of the North-west of England."—Mem. Lit. and Phil. Soc., Manchester, vol. xii.

† See "Geology of the Country around Bolton-le-Moors."—Mem. Geol. Survey, pp. 22, 23.

‡ "Geology of Stockport, Macclesfield, &c."—Mem. Geol. Survey, p. 36.

Cheshire and South Lancashire the beds occur in the form of pebbly sandstone only, while the pebbles themselves are of small size. It is therefore tolerably certain that these peculiar pebbles of quartzite have been drifted southward from a region now occupied by a portion of Scotland and the German Ocean, stretching in the direction of Scandinavia. For we are sufficiently well acquainted with the rocks both of England and the Border lands to be aware that there is no probability of the source of supply of these gravel beds having been anywhere amongst them. Dr. Buckland's idea of the source having been in the quartz rock of the Lickey is untenable on several grounds,* and especially, as it has been shown by Professor Ramsay, that this ridge of metamorphosed Silurian sandstone was hidden beneath Carboniferous and Permian strata during the period of the Bunter Sandstone. Neither can we identify the source as amongst the uplands of the south of Scotland, which are composed of rocks altogether dissimilar ; nor in the Highlands, except in such positions towards the north-western slopes, which must have been disconnected with the conglomerate area by the barrier of the Grampians.

It has often occurred to me, when viewing these great beds of gravel formed of very hard and perfectly water-worn pebbles, that these pebbles themselves must have undergone a process of trituration during more than one geological period, else they would not be so invariably bereft of all angularity. Such a view would be confirmed if we could find an *older* conglomerate formation, from the ruins of which this younger conglomerate might have been constructed. Now, I may remind the reader that the accomplished physical geologist, Mr. R. Godwen-Austen,† has shown that the Old Red Sandstone had a very wide distribution over the very region towards which we have traced the gravel beds of the Bunter Sandstone, namely the North Sea, which may have been converted into dry land during the early Triassic period ; so that all the facts I have alluded to seem to me to point to one conclusion, that the conglomerate beds, at least, of the New Red Sandstone of England have been derived from the waste of the Old Red Conglomerate which occupied the tract now submerged beneath the waters of the German Ocean, as well as certain tracts of the central portions of Scotland south of the Grampians.

This view is confirmed by the direct evidence of the identity in lithological character of many of the pebbles of the Old Red Conglomerate with those of the New Red Conglomerate of England. The great majority of the pebbles of the latter formation are composed of a peculiar "liver coloured" quartzite, highly metamorphosed, and itself giving evidence of having been formed of a coarse-grained sandstone of even more ancient date, perhaps Cambrian. Along with these are associated pebbles of bluish-green quartzite and white quartz, all of which are found in the Old Red Conglomerate of Scotland ; nor am I acquainted with any other formation in the British Isles which is capable of producing, by its disintegration, such great masses of these

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* I only refer to this idea out of respect for the great geologist who put it forth. I have no doubt, were he alive, he would long ere this have abandoned it for reasons since discovered. In his Memoir "On the Quartz Rock of the Lickey in Worcester-" shire, and of the Strata immediately surrounding it," published in the *Geological Transactions* (1819), Dr. Buckland clearly includes the fragments of Silurian and other rocks which we now know to belong to the strata of Permian age with those found in the New Red Sandstone, of which he merely states that "they agree in " substance with the quartz rock of the Lower Lickey."—Vol. v., p. 506.

† "On the Extension of the Coal-measures, &c."—Journ. Geol. Soc., vol. xii.

peculiar conglomerates as are presented by the Bunter Sandstone of Central and Northern England.

I have very recently had opportunities of examining the conglomerates of the Lower Old Red Sandstone along the southern slopes of the Grampians at Loch Lomond, and in the neighbourhood of Lesmahagow, at the southern borders of Lanarkshire, where these conglomerates have been described some years ago by Sir Roderick Murchison. In both these districts the conglomerate is composed of rounded pebbles and blocks of light pink and purple quartzite, sometimes attaining a size of 12 or 14 inches in diameter; and amongst these are a few pebbles, white quartz, and jasper. No one can compare these pebbles with those from the Bunter Conglomerate of England without being struck by their identity in mineral composition; and the comparison I have been able to make thus far confirms me in the impression I have for several years entertained, that, to some extent at least, the New Red Sandstone of England is daughter of the Old Red Sandstone of Scotland.

Although it is clear that the quartzoze gravels are an antetype of our "Northern drift," it is equally certain that most of the sandy sediment in which these pebbles are partly enclosed has been derived from regions lying to the north-west of Central England. If we draw a section from the mouth of the Mersey in a south-easterly direction towards the estuary of the Thames, it will be found that all the subdivisions, and consequently the whole mass of the Trias, become attenuated in this direction. The beds in fact form a wedge, lying diagonally across the Central counties, with the apex pointing towards the mouth of the Thames.

We have already seen that the Bunter Sandstone dies out along a N.E. line drawn through Leicestershire, while in the north-western parts of Lancashire and Cheshire the formation attains the enormous thickness of 2,000 feet;* the subdivision of the Pebble beds alone being 600 feet thick. These comparisons point to the conclusion that the sources of sediment were situated to the north-west, the direction in which they attain their greatest development; so that, during the middle stage of the Bunter period, while one ocean-current swept along beds of gravel from the north, another was contemporaneously drifting the finer sandy sediment from regions lying in the direction of the German ocean.†

CHAPTER VII.

Upper Red and Mottled Sandstone.

This is the uppermost of the three subdivisions of the Bunter Sandstone, and is so uniform in structure and composition over the whole of its range that one description will be almost sufficient. It is for the most part similar in appearance to the Lower Mottled Sandstone, consisting of soft fine-grained sandstone, generally laminated, and of a bright red or vermilion tint. Streaks and blotches of yellow or white are observable, and occasionally it is traversed by plains of current-bedding. In the neighbourhood of Birkenhead, Liverpool, and Ormskirk, the lower portion of this subdivision is red, the upper yellow, and sometimes sufficiently hard for building purposes. This

* Compare Horizontal Section, sheets 43 and 44.

† The author has shown that which is here stated of the Bunter Sandstone probably holds good in regard to all the Lower Secondary Formations.—Quart. Journ. Geol. Soc., vol. xvi., p. 63.

diversity of colouring has been shown by Mr. George Maw to be due to the presence of iron occurring in the red portion in the form of anhydrous, and in the yellow in the form of hydrous, sesquioxide.

One of the characteristics of this sub-division is the absence of pebbles of other rocks, in marked contrast to the underlying Pebble beds ; the particles of sand are also smaller, and the beds are generally soft enough to be worked for foundry moulding sand, as is done at Birmingham, Stourbridge, Wolverhampton, and Ormskirk.

This sub-division just appears at the southern termination of our district, emerging at a low angle from beneath the escarpment of the Lower Keuper Sandstone at the northern end of the Abberley Hills. At this point the Silurian and Devonian rocks appear to have formed its original boundary to the westward, in the form of a shelving shore, against which all the beds of the Trias, from the Lower Mottled Sandstone up into the Red Marl, were deposited in succession from north to south.

Stourport.—The Upper Mottled Sandstone occupies both banks of the Severn at Stourport. It is terminated by a fault along the north-west, and dips at an angle of 5° to 7° beneath the brecciated beds of the Lower Keuper, which range in a north-easterly direction, from the left bank of the Severn at Lincomb, through Hartlebury Common towards Stourbridge.* A very fine section, conspicuous at a distance, is shown on the right bank of the Severn below Stourport, in a vertical cliff, whose base is washed by the river called "The Redstone Rock." It consists of bright red sandstone, with blotches and bands of yellow and white, dipping towards the south-east at 6° or 7°. A total section of about 300 feet vertical may be here seen, and it is remarkable for the occurrence of bands of sub-angular pebbles of purple grit, quartzite, and other local rocks, the first instances I have observed of pebbles in this sub-division of the Bunter series. The occurrence of these small pieces of rocks which occur immediately to the westward amongst the hills of Palæozoic formations, is clearly due to the position which the Bunter Sandstone occupied relatively to the older rocks, which, as remarked above, was that of a deposit forming on a gradually shelving shore. The great mass of the sandy material was without doubt derived from a northerly and more distant source, but along with it were imbedded fragments of the rocks which lined the coast of the period.†

The beds of this sub-division, after disappearing beneath the Lower Keuper Sandstone between Hartlebury and Stourport, emerge towards the north-east along the southern base of the Lickey Hills, from Hagley to Blackwell Farm, where they are thrown down by a large fault which introduces the Red Marl. This fault seems to be a prolongation of the downthrow which ranges along the eastern side of the quartz rock of the Lickey.‡ At Hagley it is also traversed by the great line of dislocation which forms the western boundary of the South Staffordshire coal-field. The throw of this fault at the Bell Inn, where the Lower Keuper Sandstone is brought down against the Conglomerate beds of the Bunter, is over 200 feet, and at the village of Clent is considerably greater, as the whole of the Bunter Sandstone is brought down and concealed against the Permian beds.§ A section of the Upper Mottled

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* See Geological Survey Map, Sheet 55 N.E., surveyed by Messrs. Ramsay, Aveline, and Howell.

† The Redstone Rock is hollowed out into rude dwellings which are inhabited by a modern race of cave dwellers.

‡ See Geological Survey Map, Sheet 54.

§ See Hor. Section of the Geological Survey, Sheets 50 and 51, with "Explanation" by Professor Ramsay.

Sandstone, familiar to geologists who travel by the Gloucester and Birmingham Railway, is laid open along the banks of the steep incline below Blackwell Station. The beds consist of bright red soft sandstone dipping S.S.W. at 5° to 10°.

Another section which is worthy of notice is laid open in the railway cutting immediately south of Stourbridge Station. Here the bright sandstone of the Bunter may be observed dipping below the hard calcareous brecciated sandstone of the Keuper division, the junction being sharply defined. At this town the rock with the underlying Pebble beds yields large supplies of water for the use of the inhabitants.

Birmingham District.—The town is built principally on this dry and porous rock, which has also yielded large supplies of water from wells. The nature of the foundation may in some degree have contributed to the general healthiness of this great manufacturing town, notwithstanding its smoky atmosphere and dense population. The rock is terminated eastward along the line of a large fault which throws down the Red Marl against the sandstone along the eastern suburbs. The fault may be traced from Selly Hill in a north-easterly direction, by Egbaston, Duddeston, and Erdington towards Sutton Coldfield, and along this line the Upper Mottled Sandstone is for the most part capped by harder and coarser beds of the Lower Keuper Sandstone.

At Aston a very interesting boring has been made by the Birmingham Waterworks Company, traversing the greater part of the New Red Sandstone into the subjacent Permian beds. The details of this boring were supplied to me by Mr. Rofe, the engineer to the Company; and are as follows:—

Boring at Aston, 2 miles north of Birmingham.

		Feet.
Alluvial gravel		10
New Red Sandstone	Upper Mottled Sandstone	232
	Harder do., and conglomerate	
Permian beds	Red Marl	36
	Sandstone	10
	Red Marl	15
	Very hard sandstone	53
	Marl, with stones (breccia)	45
		391

At the base of the New Red Sandstone large supplies of water were obtained. In the above section the Upper Mottled Sandstone and Pebble beds are unfortunately classed together, so that we are unable to ascertain their various thicknesses. Very fine sections in the former subdivision are laid open in quarries both on the east and west side of the town, where the beds are worked for moulding sand.

Wolverhampton.—West of this town the Upper Mottled Sandstone occupies a wide and depressed tract of ground ranging from the base of the ridge of Pebble beds westward to the escarpment of the Lower Keuper Sandstone at Tettenhall; the thickness is here about 250 or 300 feet. One of the finest sections is opened out in the road section at Tettenhall, showing also the basement beds of the Keuper series. Further south there are excavations along the banks of the Worcestershire canal, and in roads along the flanks of Penn hill, Oreton hill, and the banks of the river Stour at Stourbridge. In many of the lanes in this part of the country, which have been furrowed deep into the soft crumbling rock by time and wear, very beautiful effects are produced by the contrast of the overhanging branches of trees, brambles, and ferns, when set off against the bright red colours of the sandstone.

Nature has here, indeed, achieved one of her highest triumphs in the art of contrasting colours, when she partially bedecks the vermilion wall of sandstone with the delicate green of the lichen and moss. After many years absence the effect of this grouping of colours under a sunny sky, and in the early part of summer, is still vividly impressed on my mind.

It would be mere wearisome repetition to describe these beds along their range into Cheshire and Lancashire, especially as they will necessarily receive some attention when we come to speak of the basement beds of the Keuper division of the Trias by which they are surmounted in these districts, and along the margin of which they are generally most clearly laid open. I shall therefore content myself with indicating a few localities where they seem to call for special notice.

Shropshire.—Hawkstone and Grinshill Hills.—The structure of this highly picturesque range of hills is illustrated by a horizontal section of the Geological Survey,* and will be more fully described when I come to treat of the Lower Keuper Sandstone. This range, together with that of the neighbouring ridge of Grinshill, was visited and described by Sir R. Murchison in "the Silurian system,"† and to this I shall again refer, as the beds of the Hawkstone Range for the most part belong to the Keuper division of the Trias. I shall here merely observe that the Upper Mottled Sandstone forms the flanks of the two more northerly escarpments, which are formed of the same beds repeated by a longitudinal fault, and underlaid by the Pebble beds of the southerly escarpment of Booley Bank (see fig. 37, p. 73). The same beds are laid open at Grinshill, where they have yielded traces of copper ore, and the following section from the "Silurian system."‡ I here reproduce,—

Section at Grinshill, Salop.

		Ft.	in.
Lower Keuper Sandstone.	1. "Fee and jay" (rubbly thin bedded rock)	13	0
	2. Flag rock, yellowish or light brown colour	19	0
	3. Sand bed called "Esk"	0	9
	4. Hard burr	2	6
	5. Coarse freestone, mottled, of yellowish and reddish colours, best building stone	9	6
	6. Grey freestone	7	6
	7. Good light yellow freestone underlain by a seam of clay	11	0
	8. Good white freestone	2	0
	9. Strong „ „	8	0
Upper Mottled Sandstone (Bunter).	10. Sandy and bad freestone	2	0
	11. Bad stone, sometimes used for walls, &c.	9	0
	12. Soft yellow sandstone, the grains of sand cemented by decomposed felspar	4	6
	13. Sandstone of deep red colour sunk through for water	222	0
		311	7

There is some uncertainty as to the exact line of demarcation between the Bunter and Keuper series, as the uppermost beds of the former are sometimes sufficiently hard for building purposes. This is the case along the range of hills which rise to the north of Shrewsbury at Harmer Hill and Ness Cliff, &c. Here the Upper Mottled Sandstone is extensively quarried and yields blocks of compact, fine-grained red sandstone, easily worked, but probably rather liable to disintegrate.

* Sheet 45, No. 2. † Page 38.

‡ Page 40. The elevation of Grinshill Hill, 632 feet, has been determined by the Ordnance Surveyors, and supplied to me by Colonel Sir H. James, R.E.

Cheshire.—The flanks of the Peckforton Hills and those of Delamere forest as far as Helsby Hill and Runcorn, are for the most part composed of Upper Mottled Sandstone, capped by the harder sandstones and conglomerates of the Keuper series. Their position here will be illustrated in a future chapter when treating of the Lower Keuper Sandstone, and the mineral character is everywhere that of a bright red or yellowish sandstone, streaked and mottled, soft and fine-grained. Copper-ore occurs, and has been to some extent worked, along the eastern flanks of the Peckforton range on the property of Sir P. Egerton of Oulton Park;* the ore has probably accumulated by percolation along the face of a large fault which, ranging north and south, forms the boundary of the Red Marl on the west, and of the Bunter Sandstone on the east.

Wirral.—Along the area occupied by this sub-division from New Brighton to Oxton Hill, near Birkenhead, the upper beds throughout nearly half the total thickness are of a white and yellow tint, while the remaining portion beneath is of the usual red colour streaked with white. The superposition of the yellow portion on the red, may be observed at the fine natural section shown at the coast cliffs called "the Red Noses," at New Brighton.

Liverpool District.—This sub-division forms the dry and healthy foundation of this great maritime town, and for a long time was, along with the Pebble beds, the reservoir for its water-supply till the increasing demand rendered this source insufficient. It is terminated along the east side by a large fault which traverses the town from north to south, and brings to the surface the Pebble beds of Kirkdale, Æverton, and Edge Hill.

Further inland the soft sandstone of this sub-division generally occupies Drift-covered valleys, stretching along the base of the rising ground which generally marks the position of the harder sandstones of the Conglomerate sub-division. They form the low, gently-sloping ground round Warrington, but rise from below the Drift clay along the flanks of the Runcorn Hills.

At Ormskirk this rock is laid open to a large extent in the cuttings of the railways. It here presents the same divisions as at Birkenhead, the lower beds being of a bright red colour streaked with white; the upper assuming the yellow and white tints of the rock at The Noses. These are quarried for building purposes near Aughton. The lower beds are well shown in Aughton Moss cutting, where they are largely excavated as material for moulding of iron castings; and for this purpose the sand is sent to Liverpool, Sheffield, and Manchester.

In the interesting cutting east of Ormskirk on the St. Helen's railway the upper beds are laid open; they are traversed by small faults, and superimposed by the basement beds of the Lower Keuper Sandstone. This section will be minutely described under the head of this latter formation (see p. 87). Sections in similar positions are visible at Scarth Hill, Cleve Hill, Aughton, Holborn Hill, and Scarisbrick quarry. At this latter place the upper beds, consisting of fine-grained yellow sandstone, are sufficiently hard for quarrying, but probably not very durable. They are cut off on the west by a large north and south fault which throws in the Red Marl; and a short distance south of the quarry is the site of the well and pumping station of the Southport Waterworks, from which a large supply of water is obtained. From Simmonds Wood Moss northward these beds form the boundary of the Lancashire Coal-field, against which they are brought by a great fault ranging north and south (see map of Geological Survey, sheet 89, S.W.)

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* A fact noticed by Sir R. I. Murchison in the "Silurian System" (1839), and by Mr. A. Aiken more than 20 years previously.

The Upper Mottled Sandstone attains in Cheshire a thickness of 500 to 600 feet,* and may be traced southwards to the neighbourhood of the Abberley Hills, along the borders of Wales and Shropshire. It also occurs, but with diminished thickness, all along the north and east of the plain of Cheshire, and southwards and eastwards as far as Wolverhampton and Birmingham; but we have here approached its easterly limits, for it is nowhere represented along the borders of the Warwickshire and Leicestershire Coal-fields, nor along the band of country which stretches in a northerly direction from the valley of the Trent at Nottingham to the Humber, and lying to the east of the Magnesian Limestone. Throughout this part of England the Conglomerate beds are everywhere surmounted by the Lower Keuper Sandstone.†

With the Upper Mottled Sandstone the Bunter Sandstone terminates upwards; and there is every reason to believe that the bed of the New Red Sandstone over the English area was elevated into dry land during the succeeding period of the Muschelkalk. This elevation, and subsequent submersion at the commencement of the Keuper stage, has left its evidences in the eroded surface, and slight unconformity, which is locally observable between the two divisions of the Trias of England, of which examples will be recorded in a future page.

CHAPTER VIII.

The Lower Keuper Sandstone and Waterstones.

Though the attempt has been made by several geologists to identify some stratum amongst the variable series of beds which underlie the New Red Marl with the Muschelkalk, it is now certain that we have no representative in England of that central division of the Triassic series; and that between the uppermost beds of the Bunter and the lowest of the Keuper there is a complete *hiatus*, often denoted by eroded surfaces and unconformity.

The basement beds of the Keuper generally consist of conglomerates or breccias, sometimes calcareous, and associated with beds of marl; these are succeeded by sandstones adapted for building purposes, and these latter by laminated sandstones and marls, which under the term "Waterstones" form the passage beds into the New Red Marl. The following may be considered as the general order of succession of the Lower Keuper Sandstone, subject to local modification:—

General Section of the Lower Keuper Sandstone Series.

1. *Waterstones* (passage beds into the Red Marl).—Brownish laminated micaceous sandstones and flags, rippled, with beds of sandy marl.
2. *Building Stones.*—Fine-grained light red, brown, yellow, or white freestones, regularly bedded, with occasional beds of red marl, producing the best building stone of this formation. Below these, in Cheshire and Worcestershire, we sometimes find a thick bed of soft red sandstone.
3. *Basement Beds.*—Coarse, irregularly bedded sandstones, calcareous breccia and conglomerate, with bands of marl and mottled calcareous beds similar to the "Cornstones" of the Old Red Sandstone.

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* See Horizontal Section of the Geological Survey, sheet 44, No. 1.

† Judging by the similarity of the composition and position of the beds, it seems probable that the Bunter Sandstone of the neighbourhood of Belfast belongs to this sub-division, viz., the Upper Mottled Sandstone.

Throughout the central and western counties the junction of the Bunter and Keuper divisions is accompanied and indicated by lines of hills and escarpments, often giving rise to varied and peculiar scenery, especially when these escarpments are reproduced by longitudinal faults, as not unfrequently is the case. I need only mention the districts of Alton, and the Churnet valley in Staffordshire ; of Stourport, Pattingham, Hawkstone and Great Ness in Shropshire ; and of the Peckforton, Delamere, and Frodsham Hills in Cheshire, to recall to the mind of the reader some of the most beautiful of the English uplands. Now, in all these groups of hill and valley there will be observed the primary form of a terraced escarpment, which is often reproduced with variations due to the presence of lines of dislocation traversing the beds either longitudinally, or transversely.

The base of the Keuper division forms, in fact, the upper of the two escarpments of the Trias in England, the lower being that of the Pebble beds at their junction with the Lower Mottled Sandstone,* and is due to a similar arrangement and composition of the strata, subsequently acted upon by elevatory and denuding agencies. It is the same causes which have given origin to the escarpments of the Oolite in Gloucestershire, and the Magnesian Limestone in Derbyshire and Notts ; and notwithstanding all that has been written "on the origin of escarpments," in these latter days, I still adhere to the views which I held when tracing these escarpments step by step over a large part of England—that they are primarily due to marine denudation.

In all the examples of escarpments I have alluded to we find the superposition of comparatively hard strata on soft, the latter forming the flanks, the former the crest ; and this is precisely the case with regard to the escarpments of the junction beds of the Keuper and Bunter divisions. The Lower Keuper Sandstone, whether in the form of a calcareous breccia, conglomerate, or "cornstone," is harder than the subordinate sandstone of the Bunter division, and the result under favourable circumstances is the formation of an escarpment along their boundary.

It will be observed from the enumeration of the strata comprised in this sub-division that they are of a varied character. It is owing to this frequent alternation, in the upper part, of sandstone and marl that the term "Waterstones" has been applied to it, because this structure of the beds is favourable to the production of springs ; but the term was first applied by Messrs. Binney and Ormerod to the occasional interstratifications of fine greyish sandstone which occur throughout the Red Marl series of Cheshire, and are well shown at Warburton. Afterwards the term was extended to the passage beds at the base of the Red Marl itself.

Having thus described the general character of these beds, we shall now proceed to trace them throughout their course from the shore of the Bristol Channel northwards and eastwards.

Stourport.—In the neighbourhood of Kidderminster and Stourport the Bunter Sandstone is lost to view, owing to the Keuper series bending round towards the west and terminating against the Silurian rocks of the Abberley Hills in regular succession. Besides this, the formation here begins to thin away in a southerly direction, as also to terminate along a tract of gradually shelving shore, ranging eastward from the flanks of the Abberley and Malvern Hills, and composed of Palæozoic rocks. Owing to this, the Bunter Sandstone, and even the

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* See ante, p. 30.

earlier beds of the Keuper series, may not have been deposited over these portions of Worcestershire, so that in some places the Red Marl may be supposed to rest immediately on the Palæozoic rocks. In proof of these views I must ask the reader to extend his observations for a moment to the shore of the Bristol Channel.

Between the southern extremity of the Malvern range and the mouth of the Wye the Bunter Sandstone entirely disappears. In a coast section on the northern shore of the Bristol Channel at Beachley we find the Lower Keuper Sandstone represented by 25 feet of thin reddish-brown sandstone resting on the highly tilted edges of the Carboniferous Limestone (fig. 33). These beds are superimposed by red marl 50 feet thick. The basement bed of the Keuper Sandstone is, as might be expected, a limestone breccia, but there is no trace of any beds referable to the Bunter Sandstone. Still further westward we have continually higher beds resting on the older rocks. West of Cardiff the Penarth, or Rhætic, series forms the base; and ultimately, as shown by Sir H. De la Beche,* and more recently by Mr. Bristow, the Conglomerates of the Lias rest directly on the Lower Carboniferous rocks.†

Fig. 33.

Coast Cliffs at Beachley, Bristol Channel.

The cliffs to the left are composed of Lower Keuper Sandstone resting on the edges of the beds of Mountain limestone which strike out from the shore in a series of small serried ridges. The banks in the distance are composed of Red Marl. The sketch is taken at ebb tide, as at high water the sea reaches the base of the cliffs of Keuper Sandstone, and the rocks of Carboniferous Limestone are submerged.

Stourport and Bromsgrove Districts.—The general trough-shaped arrangement of the Triassic beds, between the banks of the Severn below Stourport and their outcrop in the direction of the Bromsgrove Lickey, and Clent Hills, is clearly indicated by the map and sections

* "On the formation of the Rocks of South Wales, &c.," Memoirs of the Geological Survey, 1846.

† "On the Lower Lias, or Lias Conglomerate of part of Glamorganshire," Journ. Geol. Soc. Sep. 1867.

of this district accompanying the Memoir of Sir R. I. Murchison and Mr. Strickland in the "Geological Transactions."* In the centre of this trough is enclosed the saliferous Keupar marls, bounded both along the east and west by faults. The more easterly of these is a continuation of the great boundary fault of the South Staffordshire Coal-field, which passes through Hagley, and southward about a mile to the west of Bromsgrove and to the east of Stoke Prior, having a downthrow on the west side. The fault which terminates the Keuper marls on the west ranges in a nearly due north direction along the Doverdale valley, where its presence was observed by the authors above referred to.† It may be traced as far north as the section in the road west of Hartlebury Station, where the beds of the Lower Keuper Sandstone are fractured and disturtbed; to the north of this point it seems to die out. The downthrow of this fault is to the eastward. In this trough of the Keuper marls are situated the salt-works of Droitwich and Stoke.

The Lower Keuper Sandstone, is introduced by beds of breccia and conglomerate, often calcareous, sometimes hard, in other places unconsolidated, and generally introduced in the form of a low terraced escarpment rising above the soft bright sandstone of the Bunter series. This escarpment breaks off from the northern base of the Abberley Hills, and ranges in a general direction towards the north-east, passing by Hartlebury Common, Low Hill, Stone, and Pedmore Hill to the south side of Stourbridge, where it terminates along the line of a fault against Permian breccia. To the north and east of Bromsgrove it also forms at its base a slight ridge, but one less prominent, owing in part to the influence of the Hagley fault, which for some distance south of Stourbridge forms the boundary.

South and east of Stourbridge the Lower Keuper Sandstone, from its base up to the Red Marl, attains vertical dimensions seldom exceeded in any part of England. Probably we shall not err if we assign it a thickness of 400 or 450 feet; the basement beds may be regarded as an old shingle beach; the deposit of the time being intimately mixed with the detritus of the Palæozoic rocks to the westward, as well as those to the southward now hidden beneath the Red Marl. These brecciated beds are well laid open in the road section at Hartlebury Common; also at the cross roads at Bull Hill near Astley and at Dunley Hall. At Bull Hill I found the following rock-fragments, which were generally of small size and sub-angular: 1. Purple indurated grit (both angular and rounded); 2. Fine-grained grey quartzite (angular); 3. Small pieces of white quartz; 4. Slaty purple grit; 5. Green and purple quartzite (sub-angular); 6. Coarse-grained quartzite. These and similar fragments pervade the beds from the base upwards for about 200 feet.

Above this basement breccia occurs a mass of soft red sandstone, which is shown at Pansington, and the cliff on the left bank of the Severn below Lincomb, underlying a second bed of hard calcareous pebbly sandstone with bands of marl; and these again are overlaid at Ombersley and Hadley by the uppermost beds immediately underlying the Red Marl, and producing building stones of delicate red and yellowish tints, which are now being employed with good effect in the restoration of Worcester Cathedral.

The quarries at Ombersley and the adjoining parish of Hadley, which have probably been worked for a very long period, are described

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* Vol. v., see plate xxvii., section No. 5.

† Ibid., p. 340.

by Sir R. Murchison and the late Mr. Stickland in the essay already referred to. From 30 to 40 feet of section is exposed, and in the upper beds carbonaceous lamina and obscure remains of plants were found by these observers, one specimen of which was identified by Professor Lindley as the *Echinostachys oblongus* of Adolph. Brongniart. The following is the section presented by the series in descending order from the high grounds of Ombersley down to Holt Bridge, and on the banks of the Severn northwards, representing the upper portion of the Lower Keuper Sandstone, as given by Murchison and Strickland.

a. Beds of Keuper or red marl, forming the crest of Ombersley and Hadley ridge.
b. Thin bedded red sandstone.
c. Sandstone of whitish and red colour, with plants (building stone).
d. Thick masses of deep red sandstone underlaid by bands of sandy marl.
e. Alternating thin bands of coarse concretionary or fragmentary sandstone, gritty and quartzose conglomerate, and soft thick bedded dull red sandstone, the latter much predominating.

In the fine sections at Holt Bridge we have a series of evenly-bedded fine-grained brownish sandstones, with irregular partings of marl, graduating upwards into the passage beds of the Red Marl, consisting of laminated, slightly micaceous brown sandstones and red shales. There is a very slight dip towards the south-east, so that the beds spread over a wide area traversed by the deep valley of the Severn.

The Lower Keuper Sandstone overspreads a considerable area around Bromsgrove, rising at a low angle from beneath the Keuper marls to the southward, but bounded both on the east and west by large downthrow faults. A section of the beds is laid open in the cutting of the Midland Railway at Bromsgrove Station. The sub-formation in this neighbourhood acquires special interest on account of its having yielded a specimen of a peculiar fossil fish described by Sir Philip Egerton under the name of *Dipteronotus cyphus*.*

Kidderminster and Bridgenorth District.—The basement beds of the Keuper in this, the typical district, consist of bands of red marl and calcareous conglomerate passing into breccia, not unlike that at the base of the Pebble beds. It generally forms a well marked escarpment, terminating in a fault along the line of the Abberley Hills, from which point it sweeps round to the east and north. Between this fault and the Permian rocks of the Clent Hills the New Red Sandstone, as has been shown by Professor Ramsay,† lies in the form of a trough, the centre of which is occupied by Lower Keuper Sandstone. Above the calcareous base there comes a series of white sandstones and red marls, forming the main mass of the sub-division. A fine section in these beds is laid open in the cutting of the Worcester railway immediately south of Stourbridge, showing also the junction with the Upper Mottled Sandstone, which is here brought down against the Carboniferous rocks by the large boundary fault of the coal-field.

Wolverhampton.—At Penn and Oreton Hills, near Wolverhampton, the Lower Keuper Sandstone forms an isolated tract of hilly ground bounded on the north and east by faults, and outcropping to the westward along a low escarpment, the flanks of which are composed of the soft bright red sandstone of the Bunter. The basement beds of the Keuper consist of red marls and hard calcareous sandstone with pebbles,

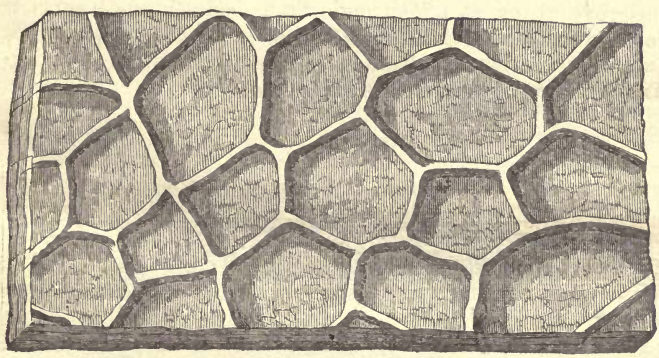
* Journ. Geol. Soc., vol. x., p. 369.
† "Explanation of Horizontal Section of the Geological Survey," sheets 50 and 51, p. 3.

forming the crest of the escarpment. A fine section is again laid open in the road cutting at Tattenhall, from the Upper Mottled Sandstone upwards. The basement beds of the Keuper are here seen to be composed of similar materials to those already described, viz., pebbly sandstone and calcareous conglomerate, resting on laminated sandstones and red marls. North of Wolverhampton the Lower Keuper Sandstone, with occasional patches of red marl, is spread over a large tract of country in nearly horizontal beds, and everywhere characterized by a calcareous and conglomeratic base. This rock, in the neighbourhood of Pattingham and Tattenhall, has been found sufficiently rich in lime to be employed, after calcination, for land and building purposes, and was originally described in the "Silurian System."* It is very clearly laid open in one of the cuttings of the Shrewsbury and Wolverhampton Railway near Shiffnal; as also at Patshull, Albrighton, and Chatwell.

The higher beds, which underlie the New Red Marl, are extensively quarried near Brewood and Penkridge; they consist of fine-grained evenly-bedded brown, sometimes yellow, sandstone, with layers of red shaley marl. They often afford instances of ripple-marks, suncracks, annelide holes and tracks, and in rarer cases footprints of Labyrinthodon; showing that the bed of the sea, or inland lake, in which they were deposited was liable to be left periodically dry. The annexed example of suncracks was taken from a slab in a quarry at Brewood Hall and

Fig. 34.

Suncracks in Sandstone.



will serve as a general illustration. For the mode of their formation we have only to observe the bed of a muddy estuary when left dry in summer time. We may then see the whole surface traversed by a network of cracks, owing to the shrinkage of the clay upon the evaporation of the moisture. Upon the return of the flood the cracks are filled in with fresh sediment, which does not always become united with the walls of the fissures, but retains its own individuality, and after consolidation comes away in *alto relievo* with the splitting of the slab.

In the neighbourhood of Rugeley and Colwich these beds are laid open in many large quarries, as they there produce very fine freestone capable of being quarried in large blocks, and often nearly white, or pale red. In other places the colour passes into yellow or light reddish brown. A good section in the basement beds is laid open in the cutting of the Trent Valley railway at Colwich.

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* See Plate 29, fig. 13.

Eccleshall and Whitmore.—West of Eccleshall the beds of the Lower Keuper Sandstone are subjected to several repetitions by a system of north and south faults, giving rise to a corresponding series of parallel escarpments. The base of the sub-division is generally red marl, upon which rests hard calcareous sandstone and conglomerate, or breccia, capping the ridges. The marl has in some instances been worked under the rock, so as to form caverns, the lower parts of which are filled with water clear as crystal. The north and south faults are crossed by one running at right angles to their direction. It is exposed to view in a deep road cutting leading down from the village of Bishop's Offley to the brook. The downthrow is on the south side, the basement beds of the Lower Keuper Sandstone being faulted against those of a higher horizon.

Fig. 35.

Section at Bishop's Offley, Salop.

North. South.

Upper Mottled Sandstone. Lower Keuper Sandstone with fault.

An interesting section is also exhibited in the canal cutting near Knighton, showing three faults, and sections in several sub-divisions of the Triassic series. A sketch is subjoined.

Fig. 36.

Canal Section, Knighton, Salop.

a. Upper soft variegated sandstone (Bunter).

F, F, F. Faults.

l. Lower Keuper Sandstone and Waterstones (brown sandstone and marl), with calcareous conglomerate (*x*) and marl at the top.

c. Conglomerate beds (Bunter).

In the vicinity of Whitmore and Norton the Lower Keuper Sandstone is generally introduced by a hard brecciated sandstone, upon which rest the usual compact sandstones interstratified with marls, which are often quarried for building purposes. In this district they are much broken by faults, and near Whitmore station form several outliers, capping flat-topped conical hills, which being richly wooded have a highly picturesque effect.

Hawkstone Hills.—This group of hills consists of two escarpments of the Lower Keuper Sandstone trending from west to east along the line of parallel faults, with downthrows to the south. The range is terminated on the east and west also by faults displacing the beds in opposite directions, the boundary of the hills on the east being formed of the Conglomerate beds of Hodnet, and on the west by the great plain

of New Red Marl. This range has been very fully described by Sir R. Murchison in the "Silurian System."*

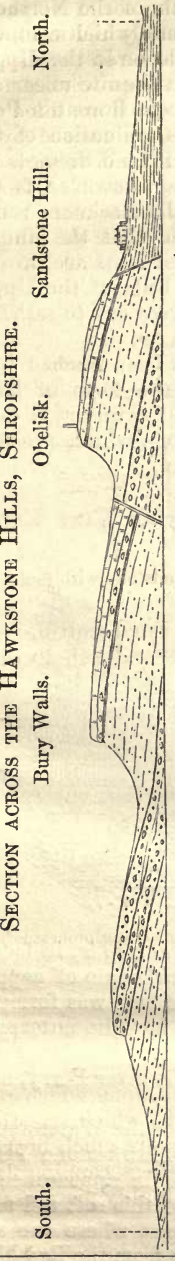


Fig. 37. Section across the Hawkstone Hills, Shropshire.

The basement beds are generally brecciated, especially along the most southern escarpment. At Weston and in Hawkstone Park the higher beds yield a fine white freestone, while those of the central and southern ridge are invariably of a light red colour.

The uppermost beds consist of thin regularly-bedded brown sandstones, slightly calcareous, occasionally becoming soft, and of a red colour.† The following horizontal section will serve to explain the general structure of these hills.

Another range, composed of the same rocks as those just described, extends from Preston Brockhurst to Middle, the highest point being at Grinshill Hill, which rises about 400 feet above the plain. Here the Lower Keuper Sandstone yields a remarkably fine white freestone, the quarry presenting a face of 100 feet in depth of rock remarkably homogeneous both in texture and colour, a section of which, taken from the "Silurian System," has already been given. These beds have yielded to Professor Owen remains of *Rhyncosaurus*.‡ In this neighbourhood the Upper Mottled Sandstone is also quarried, the highest beds, both here and at Harmer Hill and Ness Cliff, being found sufficiently hard for general building purposes. Inside the Grinshill range, and resting upon several feet of marl, there occurs a stratum of blueish-grey argillaceous rock, which causes some uncertainty with regard to the proper position of the boundary line between the Keuper Marl and Waterstones. In the map the line has been drawn so as to include the rock bed in the Marl. The position of the rock with reference to the adjacent beds is fully shown in the road section at Alderton.§

Isolated escarpments of the Keuper Sandstone, ranging north and south, occur farther to the west at Ruyton and Rednal. As the dip of these hills is eastward their presence must necessarily be considered as the result of faults which cause a downthrow of the beds, together with strips

* Pages 37, 38, and plate.

† The calcareous nature as well as the stratigraphical position of these beds led the author of the "Silurian System" to suggest that they might indicate the position of the Muschelkalk.

‡ See ante, p. 6.

§ This bed is specially noticed in the "Silurian System," and seems somewhat calcareous.

of the Red Marl formation, against beds of the Bunter Sandstone. What the precise strata may be which bound these Keuper areas to the eastward it is impossible to say. Owing to the depth of the Northern Drift, rock is only visible in one spot, viz., in the lane which connects Great and Little Ness. The section is considered to be in the Upper Mottled Sandstone. Owing also to the same cause it is quite uncertain what strata occupy the area stretching northwards from Boreaton Park to the banks of the Dee at Bangor. The western termination of the great basin of the New Red Marl from Harmer Hill northwards for several miles is likewise extremely uncertain. Owing, however, to the absence of any escarpment such as that which generally marks the range of the Lower Keuper Sandstone, it appears probable that the line of boundary is a fault, by which the soft beds of the Red Marl are thrown down on the east against the almost equally soft beds of the Upper Mottled Sandstone. Such an hypothesis appears necessary to satisfactorily explain the absence of any physical feature.

West Cheshire.—At Grug Hill a large quarry has been opened in a fine white freestone, the beds of which occur in the form of large wedges. At Lane End there is exposed to view in a quarry a fault between the Red Marl and Lower Keuper Sandstone which presents

Fig. 38.

Sketch showing a Lode in the Waterstones at Lane End, West Felton, Salop.

phenomena of more than usual interest. The *Slickenside* is, in fact, a lode containing a considerable quantity of green carbonate of copper, and some of the oxides of iron and manganese. The lode was formerly worked by means of a shaft sunk through the marl, but the enterprise proving unremunerative the works were abandoned. Another fault, also a lode, is seen in a quarry at the west bank of the river Perry, near Boreaton Park.

The town of Malpas is built upon the higher beds of the Waterstones, which here, as also in some places amongst the Hawkestone Hills, occasionally change into a soft red sandstone similar in appearance to that of the underlying sub-division. The position of this soft red rock is shown in a section in Simmond's Lane near Malpas, where the soft red sandstone may be seen separated by but a few feet from the Red Marl itself, and is, consequently, only a part of the Lower Keuper Sandstone.

Overton Scar is a natural escarpment of these beds, and is composed of white and light red sandstone resting on calcareous cornstone and breccia, forming the basement of the sub-division. In the grounds of Edge Hall these beds are quarried and produce a fine white freestone.

Fig. 39.

THE PECKFORTON HILLS AS VIEWED FROM THE NORTH.

The Rock of Beeston Castle in front; behind, that of Peckforton Castle. In the centre, the highest point in Raw Head, about 1,000 feet above the sea in height; and on the extreme right, Carden Cliff.

All these terraced escarpments are formed of Lower Keuper Sandstone and Conglomerate resting on the upper beds of the Bunter Sandstone.

The Peckforton Hills, Cheshire.

This range of hills, which is represented in the frontispiece, when seen at some distance from the north, is one the boldest and most elevated of which the New Red Sandstone can boast. It is bounded both on the north and south by faults, the downthrows of which are on those sides respectively; while within these boundary lines, the basement beds of the Lower Keuper Sandstone, reposing on the Upper Mottled Sandstone of the Bunter division, form a series of escarpments, for the most part ranging from north to south, and at intervals intersected by transverse valleys more or less dependent on lines of dislocation.

Carden Cliff, and a parallel ridge to the west, form the extreme westerly limits of the range. These, however, are mere reefs or outliers thrown in by faults, (see horizontal section, Sheet 44). The range itself is properly defined within the broken escarpment, which, commencing at Duckington, extends northward to Peckforton Castle.

Along the east, the range is abruptly terminated by a great fault crossing from the N.N.E. near Beeston Castle to the S.S.W. beyond Malpas.* Its position is marked along the whole district by the outburst of springs, from one of which the "Town well" of Malpas is abundantly supplied. West of this fault for an average distance of a mile, water is very scarce, and wells sunken at some of the farms to considerable depths have failed to afford the needed supply. This is owing to the great thickness of the Upper Mottled Sandstone, which forms an admirable filter, but is as porous as a sieve. The boundary fault, like the case already referred to at West Felton in Salop, is metaliferous, producing principally green and blue carbonate of copper, and the oxides of manganese and iron. The vein-stone, or slickenside, consists of white quartzose rock, with occasionally calcspar, which has probably been infiltered into the fissure from the sides along with the metallic substances. The lode at the time of my visit (1857) was worked at Gallantry Bank along a space of 400 yards in three shafts, and the inflow of water had necessitated the erection of an engine and pump at the south shaft. The lode is on the property of Sir P. Egerton, Bart., F.R.S., who some years since informed me of the existence of copper ore amongst the hills. Its presence here, however, seems to have been long known, as I find a notice of it in Mr. Holland's Memoir "On the "Cheshire Rock-salt District" published in the year 1811.†

Whoever has studied the features of this noble range of hills cannot fail to have observed the exceeding gracefulness of the outline formed by the sandstone along the flanks of the escarpment. Commencing at the base, the slope begins with a gradual ascent, which increases in a quasi-parabolic curve to the crest of the ridge. The curve is generally regular and unbroken, and ascends to the base of the cliff formed by the calcareous breccia of the Keuper in one graceful sweep. Numerous examples may be observed in the boldest part of the range east of Harthill, and at Bulkeley and Bickerton Hills.‡ But to the naturalist the most interesting part of the range is that along the flank of Raw Head, where nature has preserved a space which she can call exclusively her own. The escarpment here rises to a height of nearly 500 feet

* This fault is marked in the Geological Map of Sir R. Murchison appended to the "Silurian System." In the section (p. 46) of the Peckforton Hills it will be observed that there are two distinct fractures, and thus the whole extent of the vertical fall, which probably exceeds in this position 1,000 feet, is equal to the sum of the downthrows of the two faults.

† Geol. Trans., vol. i. p. 39.

‡ The elevation of Bulkeley Hill, as ascertained by the Ordnance Surveyors, and furnished to the author by Col. Sir H. James, is 729 feet.

from the valley in one bold sweep, and is scooped into a series of furrows, bounded by mural faces of hard sandstone, which project forward in tabulated bluffs, or else sweeps down in gracefully curved slopes. At a distance the lines of bedding in the red coloured sandstone, where it stands in perpendicular walls, or bursts from beneath the dark purple heather, are distinctly visible; in such cases the contrasts of natural colouring are admirable. Some of the features I have here attempted to describe will be observed in the sketch which forms the frontispiece to this Memoir.

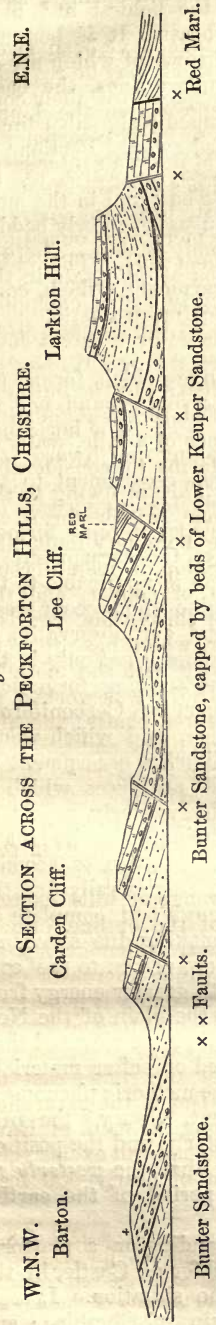


Fig. 40. Section across the Peckforton Hills, Cheshire.

The loftiness of the Peckforton Range is due, partly to the hardness of the strata which form at once the tabulated areas of the summits, and the basement beds of the Lower Keuper Sandstone. Where crossed by the horizontal section (Sheet 44)* at the old encampment of Larkton Hill, the height is 935 feet, but Raw Head is even higher. From the whiteness of the rock which crowns this latter hill, and has given origin to its name, it may be called the *Mount Blanc* of the range. The height of these hills is also attributable to the great boundary fault, along which they have been upheaved on the eastern side, and which causes them to rise in so abrupt a form along the margin of the central plain of Cheshire. In this character they appear when viewed from the opposite side of the plain, on the flanks of the Staffordshire Coal-field, where they present an appearance similar to that of the Cotteswold Hills, when seen from the Malvern Ridge, across the plain of Gloucester.

The general structure of this range has been illustrated by a horizontal section,* which I levelled across this tract of country from Denbighshire in 1858, and which, in a diminutive form, is represented in the annexed woodcut.

The general succession of the Keuper series here is as follows :—

		Feet.
Keuper Series.	New Red Marl (seen east of Lee Cliff)	50
	Brown regularly bedded micaceous flagstones and red shales (Waterstones), seen at Broxton Hall	150
	Hard red and white freestones, quarried for building purposes, and used in the construction of Peckforton Castle	200
	Hard calcareous breccia or conglomerate, full of current bedding, and resting on a thin band of marl	50
Bunter.	Upper Mottled Sandstone. Soft fine grained, bright red and yellow sandstone, forming the flanks of the escarpments and parts of the plains	500

* No. 1, Sheet 44, published by the Geological Survey.

The beds of calcareous breccia at the base of the Keuper Series generally rest directly on the Upper Variegated Sandstone, or are separated therefrom by a bed of marl, giving rise to springs, as at Burwardsley and Bickerton Hill.

The higher beds of the Lower Keuper Sandstone have been swept from off the greater portions of the high ground, which may be regarded as an old plain of marine denudation, and in consequence of their comparatively softer character, the strata which are immediately subordinate to the Red Marl have been broken up and carried away. Portions of these beds, together with a few feet of the overlying marls, as, for instance, to the east of Lee Cliff, are nevertheless to be found in the more protected places of these hills; and consist of the usual regularly bedded brown flagstones, alternating with red and grey sandy shales. There is, on the whole, a strong resemblance in the succession of the strata in this district and in that of Bridgenorth, and consequently a good exemplification of the persistency of lithological character in the Triassic strata over considerable areas.

The view of the eastern portion of the range which forms the frontispiece to this volume is taken from some rising ground not far from Broxton Clump, near the base of Bickerton Hill. The horizontal section (Sheet 44) crosses at this point. Looking northward, the range appears as a table land, presenting a steep escarpment to the west, and forming a succession of bays and headlands suggesting the resemblance to a line of sea coast, which, I believe, it once formed. It may be here remarked that the great majority of the escarpments of this range face the west, and the same observation is applicable to the whole of the principal escarpments overlooking plains which occur westward of the coast of the Irish Sea. If we extend our observation to other parts of the country we find the same phenomena, not only in the case of the New Red Sandstone, but also characterizing formations both older and more recent. The noble rampart of Carboniferous Limestone which overlooks the vale of Llangollen, and which would form a good natural boundary for Wales, the Silurian escarpment of Wenlock Edge, the ranges of the Oolite and Chalk, are cases which at once occur to the mind. The persistency of the westerly aspect of these escarpments is no doubt principally to be attributed to the fact of the dip of the beds being towards the east. But in order to account for the steepness of these cliffs, and the fact that we generally find the denudation of the strata to have been more thorough and complete on the west than on the east of these escarpments (making due allowance for the difference in hardness of the rocks), we are driven to the conclusion, that the ancient sea has been impelled with greater energy from the west than from the opposite direction. Thus the plain of the New Red Marl on the east side of the Peckforton Hills is more elevated than the sandstone district on the west, though composed of softer materials. The question is of interest as throwing light on the meteoric phenomena of the Drift period. As has been shown by Lieut. Maury,* the prevalent winds of the Atlantic and Europe are westerly, and the position of the escarpments of this country seem to show that the *westerly set* of these winds had already commenced at this period of the earth's history.

At the northern extremity of the range, and standing on a platform of Lower Keuper Sandstone has been erected Peckforton Castle, in the old feudal style which harmonizes well with the situation. It commands an extensive view over the central plain of Cheshire; and

* "Physical Geography of the Sea," 6th edit., plate viii.

looking to the northward across a deep valley, or strait, the rock of Beeston Castle, rising in a solitary mass from the surrounding plain, and crowned with ruins, forms a striking object. This rock is formed of the basement beds of the Keuper surmounting Bunter Sandstone, and presents a precipitous mural face to all points of the compass except the east. That it once joined the escarpment of the Peckforton range is evident, both from the similarity of the position and nature of the beds. The valley, therefore, which separates them now has, therefore, been swept out by that old sea, which overspread the plain, and lashed the cliffs of the Peckforton hills with its waves.

Beeston rock is, in reality, the northern termination to the range in the form of an advanced breastwork; and around its base, as well as that of the hills to the southward, are spread thick beds of gravel and boulder clay belonging to the Glacial period, which conceal the strata for a considerable distance to the northward. I was, therefore, for some time, at a loss to account for the abrupt termination of the range, though often suspecting it to be due to the presence of a fault crossing at the base of the cliff. This view was fully confirmed when I came to examine the district around Tarporley; for there I found, in a quarry situated a little east of the village, the higher beds of the Waterstones emerging from below the Red Marl, and dipping at an angle of 9° towards the south-east, in a direction which would carry them right to the base of the cliff. This fault is marked on the Geological Map, and produces a displacement of about 600 or 700 feet with a downthrow to the north.*

Delamere Forest.—The Lower Keuper Sandstone is spread over a large area of Delamere Forest, in nearly horizontal beds, often repeated by faults. The general order of succession is well represented at Longley Hill, where crossed by the horizontal section of the Geological Survey (sheet 43); this hill rises about 575 feet above the sea-level.

Lower Keuper Sandstone, Longley Hill, Delamere Forest.

		Ft.
Red Marl	Lowest beds. Grey and red micaceous shales ripple-marked (seen at Heald).	
Lower Keuper Sandstone.	(*Waterstones.*) Thin bedded brown micaceous flagstones, regularly bedded, and rippled, with footprints of *Labyrinthodon*	140
	Red sandy shales, &c.	45
	Yellow, white, and brown freestones (building stone) with partings of shale	210
	Sandy marl (not well shown)	8
	Basement beds (better seen at Simmonds' Hill and Avanley Cliff), coarse red freestones with scattered pebbles and partings of sandy shale	137
	Total thickness	540

* Before taking leave of this district I may mention that faults can be viewed in the following localities:—At the east side of Stanner Nab, in a cliff south of the "stone quarry" on Bulkeley Hill, in ravine south of Badnook wood near Harthill, in lane at Bickerton, in quarry at the foot of Larkton Hill, south of Broxton Clump, in a pit close to the lane east of Larkton, in the brook south of Edge Hall, and in two places in the brook at Lower Threape. As no escarpment appears till we arrive at Kelsall, it is probable that between that locality and the Peckforton Hills the waterstones are bounded by a fault throwing them down against the Upper Mottled Sandstone. One, of which it is probably a continuation, is exposed to view in a lane north of the village.

It is doubtful whether this subdivision of the Keuper series attains so great a development in any other part of England.

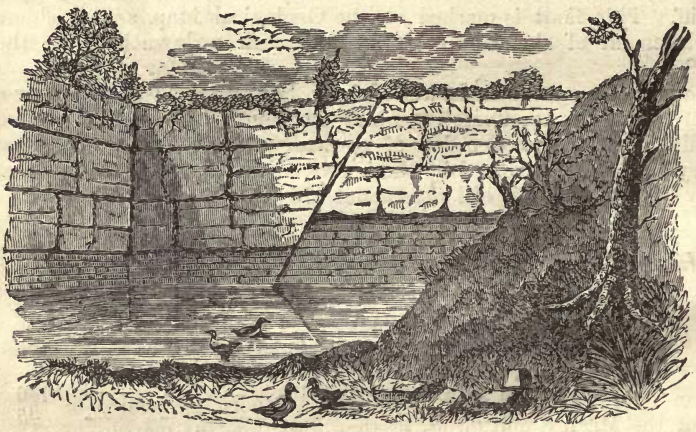
Towards the northern portion of the Forest the higher beds of the Waterstones, and the lower of the Marls become highly micaceous.

At Delamere, and the east side of Eddisbury Hill, lower beds of this subdivision occur. They consist of massive brown sandstone, frequently containing pebbles, and are underlaid by marl, which is seen in a quarry close to Delamere rectory, forming, perhaps, the basement of the subdivision. These beds are quarried in several places. At the foot of Longley Covert there is a quarry, wherein may be seen a bed of hard calcareous breccia, in which fragments of crinoidal stems, probably from the Carboniferous Limestone, were found.

The woodcut (fig. 41) represents the waterstones as seen in a small quarry south of Delamere; and in the same beds at Eaton, Sir P. Egerton pointed out at the time I was surveying the distinct footprints of the cheirotherian reptiles, referred by Professor Owen to the genus *Labrynthodon*.

Fig. 41.

Quarry at Delamere in the Waterstones.



The beds shown in this quarry consist of brownish-red evenly bedded micaceous sandstones resting on strata of red sandy marl. A small fault traverses the rock.

Freestone is extensively quarried all along the escarpments, to their termination in the bold cliffs which overhang the valley of the Weaver. The beds are generally of a light red colour, containing interstratifications of soft red sandstone and marl, which produce several minor escarpments and tabulated areas. On the hill above Frodsham, one of these soft beds attains a thickness of about 50 feet, and might be supposed to belong to the Upper Mottled Sandstone, were it not that hard reddish freestone is seen coming out from beneath it, at the foot of the hill.

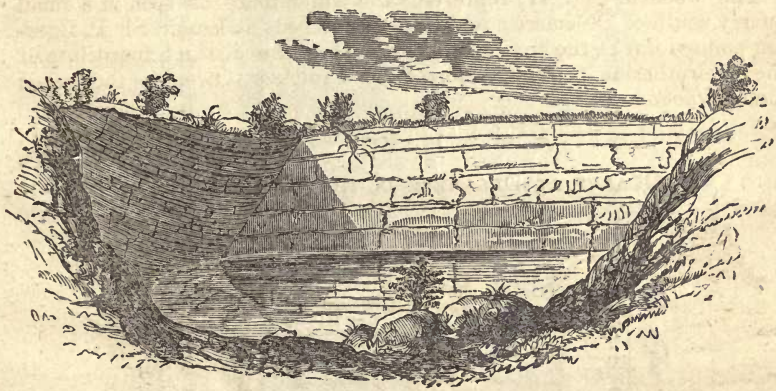
At Manley, quarries have been opened in the Lower Keuper Sandstone, which in that locality yields a very durable white freestone, producing blocks of handsome building stone of any required size. The beds are terminated on the east and west by faults, which isolate them from the general area of the formation. The western fault is visible

in two places near the quarries, along with the slickensides. The eastern fault is only inferred, as the beds at Manley dip under those which form the next escarpment to the eastward, though both are on the same geological horizon.

The lower beds of the Red Marl in this district are rather arenaceous, and have a highly laminated structure. They are often ripple-marked

Fig. 42.

FAULT IN THE RED MARL NEAR KINGSWOOD FARM, DELAMERE FOREST.



and micaceous, and numerous large pits have been opened, especially in the northern portions of the Forest.

The annexed sketch represents a fault in the Red Marl. The side of the pit directly facing the observer is the face of the fault, and the friction on the downthrow side has caused a small synclinal in the strata.

The range of hills which overlooks the southern extremity of the estuary of the Mersey, and forms, in that direction, the margin of the central plain of Cheshire, have a very bold aspect when viewed from the west. Helsby Hill, the nearest in the sketch (Fig. 43), rises to the height of 472 feet above the sea. The base of the cliffs forms the lower boundary of the Keuper ; and as we find the Red Marl not far distant from the edge of the escarpment, we can make an approximate estimate of the thickness of the Lower Keuper Sandstone, which appears to reach nearly 300 feet, while the Upper Mottled Sandstone is considerably greater.

The valley which intervenes between Helsby Hill and the second range is excavated in the line of a fault, a continuation of that which throws down on the west the freestone of Manley against beds of the underlying subdivision.

In the extensive cutting in the Manchester road near the bridge of the River Weaver at Frodsham a beautiful anticlinal in the higher beds of the waterstones is exhibited (Fig. 44). A stratum of marl 15 feet thick underlies regularly-bedded brown sandstone, which occupies a position immediately below the Red Marl proper. This lower marl bed breaks into cubical fragments, in which respects it differs from the true

red marls, which, as may be observed in the sections along the banks of the river, are of a slaty or highly laminated texture.*

Fig. 43.

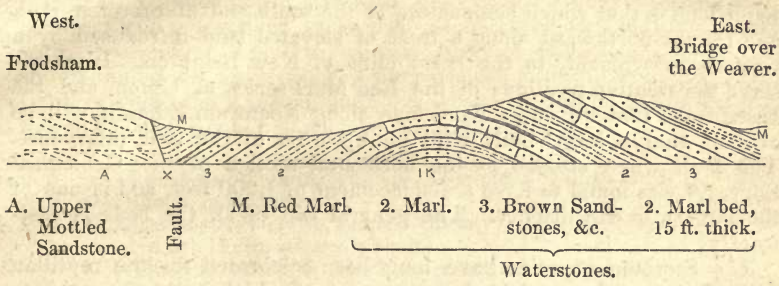
View of Helsby and adjoining Hills, Cheshire. Seen from the West.

These cliffs overlook the estuary of the Mersey and the plain stretching westward towards the estuary of the Dee. They are formed of hard calcareous pebbly sandstone belonging to the Keuper series, surmounting the soft red sandstone of the Bunter, of which the flanks of the escarpment is composed.

* A by no means rare instance of useless expenditure of money arising from the want of knowledge of the geological structure of the country and the relationship of its various strata, occurred in this district a few years since, in an attempt which was made to obtain rock salt. The boring was made where the present salt-refining works are situated, not more than a quarter of a mile from the above section, and through the very same beds. Since my visit to the Marston salt mine near Northwich in 1852, I have been of opinion that the salt rock is situate at the base of the Red Marl, and in

Fig. 44.

SECTION SHOWING ANTICLINAL NEAR FRODSHAM, CHESHIRE.



The Peninsula of Wirral, Cheshire.—The Lower Keuper Sandstone, surmounted at Greasby by the Red Marl series, occupies several isolated tracts between the estuaries of the Mersey and the Dee.

The general succession is similar to that in Delamere Forest, and is well represented, in the lower part, at Storeton Hill, and in the upper, at the village of Greasby, where the lower beds are prevented by a fault from reaching the surface; the general succession may be described as follows :—

Lower Keuper Series, Wirral.

(*a*) Thin bedded brownish sandstones, rippled and micaceous, with beds of sandy marl (*waterstones*) -	450–550 ft.
(*b*) Massive white, yellow, and light red freestone, with occasional bands of red and grey marl, quarried for building at Storeton, Bidston, and Oxton Hills - - - - - - -	
(*c*) *Basement bed.* Coarse yellow sandstone and conglomerate of small quartz pebbles, much current-bedded, and full of cavities often filled with blueish clay - - - -	

Heswell Hill.—The Lower Keuper Sandstone here consists of reddish fissile sandstone, occupying the position of the building stone of other localities, resting on two beds of coarse grit and conglomerate, separated by soft red sandstone, and thus giving rise to two minor escarpments. The difference of colouring of the beds here, as compared with their representatives at Storeton and Bidston Hills, shows how variable is this feature in sandstones, and how little it is to be depended on as a means of identification.

Greasby and Upton.—The highest beds of the Lower Keuper Sandstone, together with the superincumbent Red Marl series, are here let down between two faults, one of which ranges along the valley of the Fender Brook. They are of considerable thickness, and the transition from the waterstones into the Red Marl is so gradual that I found it difficult to form an opinion regarding the age of these beds where sunk

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this I am confirmed by Mr. Ormerod. If this be the true position of the salt bed, it is evidently useless to attempt to reach it through the Waterstones and underlying strata; yet such an attempt was made by a person well acquainted with the mine section at Northwich. This case shows the insufficiency of *local* knowledge when unaccompanied by that higher kind which enables the possessor to generalize for any given locality.

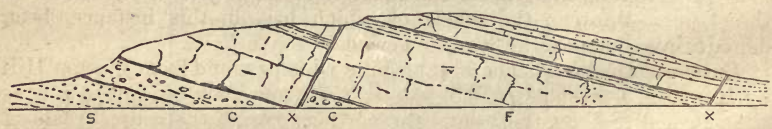
through to a considerable depth at the village of Upton in a well belonging to Mr. Inman, of Upton Hall.

Storeton and Bidston.—The most important area of the Lower Keuper Sandstone is that which commences at the south end of Storeton Hill, and ranges northward along a tract of elevated land introduced by a westerly escarpment, to the coast cliffs of New Brighton. If we observe the relative positions of the Red Marl series at Upton, and the base of the Lower Keuper Sandstone along Noctorum Edge, it will be evident that a large fault with an upthrow to the east intervenes. This fault where crossed by the horizontal section of the Geological Survey,* was found to have a displacement of 1,200 feet, and is one of the largest in the district. The general dip of all the beds is eastwardly.

The Storeton quarries have long been celebrated for the reptilian footprints they have yielded, an account of which was presented to the Geological Society of London, in 1838, by Mr. J. Cunningham, F.G.S., and Mr. J. Yates. The former of these observers has since found apparent impressions at Bidston Hill of even larger dimensions. Sun-cracks and little pits, supposed to have been caused by showers of rain, may also be observed. The following woodcut represents the beds at the fine freestone quarry of Storeton Hill.

Fig. 45.

Lower Keuper Sandstone, Storeton Hill.



S. Lower Mottled Sandstone. C. Conglomerate at the base of the Keuper series. F. White freestone with bands of marl. × × Faults.

The ridge of Wallasey is separated from that of Flaybrick and Bidston by the valley of Wallassey Pool, but is composed of similar beds. A good section is shown in the road cutting at the village, representing the junction of the Keuper and Bunter Sandstones. The former consists of hard coarse white grit with small pebbles, and interposed softer beds, resting on soft yellow sandstone, fine-grained, and current-bedded. The dip is here also towards the east; and at Birkenhead the whole of these beds are terminated to the eastward by a large up-cast fault, which ranges north and south through Tranmere to the mouth of the Mersey on the west side of Black Rock Battery.† Along the eastern side of the fault the red sandstones of the Pebble beds of the Bunter division are brought to the surface.

Liverpool.—Along the western side of the Æverton Fault, described in a former page,‡ the Lower Keuper Sandstone has been brought in along two narrow bands, one of which is due to a secondary fault,

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* Sheet 68. This fault can be well determined at Woodchurch, and is a little to the west of the spot chosen by Mr. Bateman, C.E., for a new well to supplement the supply from the Flaybrick well.

† The surface of the sandstone along the eastern slope of Bidston Hill is beautifully glaciated by striæ, ranging N. to S., first described by Mr. G. H. Morton, F.G.S.

‡ Page 58.

which passes close to the Lime Street station; the amount of throw is here about 400 feet. The throw of the Æverton Fault is about 1,500 at the centre of the town.*

Mr. G. H. Morton, in his work on "The Geology of Liverpool," has very fully described these beds as observed in the three tunnels which pass under the town, namely, those of Waterloo, Lime Street, and Wapping, all converging at their eastern extremities at Edge Hill. In all of them, the Everton fault was observed, and on the downthrow side the Lower Keuper Sandstone series, as follows:—

	ft.
a. Upper beds (Wapping Tunnel). Laminated reddish sandstones and shales - - - - -	150
b. Lower shale series (St. James Cemetery). Grey, white, and reddish laminated sandy shales - - -	50
c. White and yellowish freestone, resting on harder pebbly sandstone - - - - - -	175
	375

All over this district, the basement beds of the Keuper series rest on a highly eroded surface of the Bunter, and we have here evidence that there has been considerable denudation of the Upper Mottled Sandstone of the latter division, before the more recent beds of the Keuper were deposited upon it; for at the southern side of the town, as pointed out to me by Mr. Morton, the Keuper conglomerate is found resting on the *red sandstone*, which, as may be seen at the Red Noses on the sea coast at New Brighton, underlies a considerable series of *yellow sandstone* of the Upper Bunter; the whole of which has, in this instance, been denuded away before the Keuper period.

Runcorn District.—The broken hills which extend from Weston Hill by Runcorn, Daresbury, and Appleton to Lymm, may be considered as the physical prolongation round the northern rim of the central plain of Cheshire of those ranges of Delamere and Peckforton, which form its western limits. They are composed of identical strata, namely, the Lower Keuper Sandstone, superimposed on the upper beds of the Bunter, and, though broken through by fractures which generally range along north and south lines, they ultimately sink below the Red Marl series of the plain to the south. These lines of fracture are generally accompanied by corresponding features of valley or ridge, and are illustrated by a diagramatic section drawn from Weston point to Halton in a former Memoir of the Geological Survey.†

At Weston Quarries, the junction beds of the Keuper and Bunter series are frequently exposed to view in the face of the rock, and require close examination in order to detect the line of separation. The beds of the newer formation will be observed to be less bright in colour, of coarser texture, and not so liable to disintegration as those of the older. One bed in the Keuper division is peculiarly rich in the remains of reptillian footprints, and of these a very interesting specimen of Labyrinthodon, showing the structure of the under surface of the foot, was obtained by Mr. J. W. Kirkham, and is figured and described by Professor Williamson, F.R.S.‡

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* Horizontal Section of the Geol. Survey, sheet 68.

† "On the Geology of the Country around Prescot, Lancashire," 2nd edit., p. 16.

‡ Geological Journal, vol. xxiii., p. 56. Professor Williamson, from the scaly appearance of the foot, considers the animal to have been allied to the Saurians rather than to the Batrachians.

A quarry at Appleton exposes a section of 50 feet of light-red freestone with partings of marl. The lowest bed contains pebbles of quartz. The higher beds are admirably exhibited in the road cuttings at Preston-on-the-Hill and Daresbury. They consist of about 200 feet of ripple-marked flagstones interstratified with thick beds of sandy marl, and separated from the freestones by soft bright red sandstone visible in the high road south of Hollin Hedge, and along the brook east of Appleton Hall.

At Lymm the waterstones have been long celebrated for the abundance of the reptillian footprints and other subærial phenomena they exhibit.* The whole series from the base of the Lower Keuper Sandstone into the Red Marl may be viewed here along the banks of a dell which traverses the centre of the village. The upper flagstones are largely quarried, and at the Windmill quarry we obtain the following section.

Section of the Waterstones.—Lymm.

a. Boulder clay - - - - - -	4 to 6 feet.
b. Brown thin-bedded marly sandstone, micaceous, splitting into ripple-marked layers; with sun-cracks and vermiform markings - - - - - - -	8 „
c. Similar beds of a grey colour - - - -	8 „
d. Thick bedded brown and grey flags, the upper surface affording frequent instances of Labyrinthidont footprints -	4 „

The direction of the ripple over a large bed was found to be from east to west. The Red Marl of this district is generally thickly overpread by Northern drift, so that sections are seldom met with. Along the south bank of the Weaver, from Frodsham to Dutton Viaduct, there are numerous indentation and gullies in the banks, which are cut down through the Boulder clay and sand into the beds of Red Marl. The beds here are remarkably shaley, highly micaceous, and finely rippled; characters already noticed in the same beds at Delamere Forest. Sections are also shown in the cuttings of the Frodsham and Warrington railway at Sutton and Hindley Wood at both ends of the tunnel. Here pseudomorphous crystals of chloride of sodium occur, and the beds are frequently traversed by small regular current-ripples about one inch in diameter.

Ormskirk.—The district around Ormskirk affords several very interesting sections in the Trias, and it is the only one with which I am acquainted where we obtain in one section visible evidence of the unconformity of the Bunter and Keuper divisions. The deep sections opened out by the Ormskirk and St. Helen's Railway, if not everything that could be wished for the purpose of demonstrating the discordance between the two divisions of the Trias, are probably as satisfactory as the nature of the rocks admit of.

The section commences half a mile east of Ormskirk, from which point it extends for about 600 yards, offering a very fine exhibition of the strata. The basement bed of the Keuper Sandstone consists of coarse light red or brown grit, containing small pebbles of white quartz, and traversed by planes of current-bedding. It rests on a distinctly eroded surface of the Upper Mottled Sandstone of the Bunter series, and the line of junction may be traced for half a mile along the road on Greetby Hill, and continuously along the railway section. Upon a careful examination the Keuper Sandstone will be found to overlap successive

* Binney, Quart. Journ. Geol. Soc., vol. xii., p. 352. Rawlinson, vol. ix., p. 37.

beds of the Bunter, which are distinguishable principally by colour, but also by other mineral characters. A drawing coloured so as to present a faithful copy of the actual section would be the most satisfactory method of illustrating this, to all appearance, unconformable overlap of the lower division of the Trias, but it is hoped that the annexed woodcut (fig. 46) which has already appeared in a former Memoir,* and is here re-produced, will sufficiently illustrate the phenomena in question.

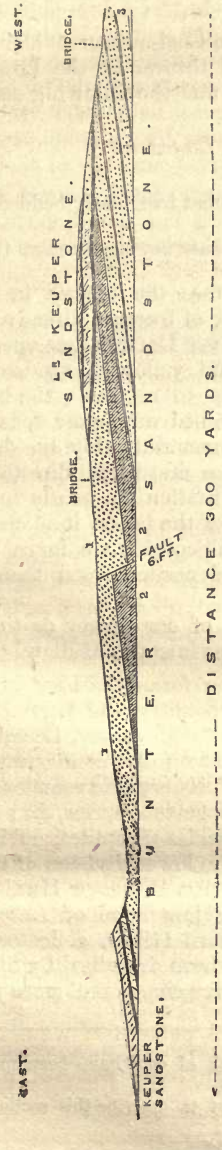

Fig. 46.

SECTION IN RAILWAY CUTTING NEAR ORMSKIRK, LANCASHIRE, SHOWING THE UNCONFORMABLE OVERLAP OF THE KEUPER ON THE BUNTER SANDSTONE.

In this section the Lower Keuper Sandstone occurs at the west and east extremities, but is absent in the centre, although close above the railway cutting. At the eastern part it rests on the yellow beds (marked I.), below which there is a bed of more compact dull red sandstone 10 feet thick (2), which with 1 is entirely overlapped, and at the western side the Keuper Sandstone again appears capping the beds (marked 3), consisting of bright red sandstone streaked with yellow bands. At this part the dip of the Bunter is 6° east, that of the Keuper being considerably less, or about 2°.

At Scarth Hill the superposition of the Keuper on the Bunter is well shown in the excavations in the beds of the latter, which are largely used in the iron districts as material for moulding. The base of the Keuper Sandstone rests everywhere on an eroded surface of the Bunter, filling in hollows and channels. This character of the upper surface of the Bunter is one evidence, amongst others, that the bed of the sea was elevated into dry land during the deposition of the Muschelkalt. During this elevation, or upon the subsequent submergence at the commencement of the period of the Keuper, the waterworn surfaces were produced, and a considerable portion of the strata was removed by denudation, as would appear from the section near Ormskirk.

There are several other small tracts formed of the basement beds of the Keuper in this neighbourhood which generally owe their preservation to downthrow faults. A small outlier caps the higher part of

* "Geology of Wigan," 2nd edit., fig. 9, p. 31.

Ormskirk. The same beds are brought in at Lathom New Park by the great boundary fault of the Carboniferous rocks, which throws down the whole Bunter series against the Lower Coal-measures or Gannister beds. Keuper sandstones and shales are brought in by a north-south fault at Cleve Hill, and the same fault throws in the Red Marl along the western side of Scarisbrick Park against Upper Mottled Sandstone. The beds, which consist of red and grey marls with bands of white mudstone (Upper Keuper Sandstone), may be observed in a brick-yard near the Paddock Plantation.*

The great fault which brings up the Coal-measures along Croxteth Park upon its prolongation northward throws in the Lower Keuper Sandstone at Maghull. In a quarry we find the following section :—

Section at Maghull, Lancashire.

	Feet.
a. White fine-grained sandstone, somewhat irregularly bedded -	14
b. Soft white and red sandy shales - - - -	4
c. Hard, thick bedded, white freestone, base not shown more than	5

There is a small fault which traverses the quarry in a direction N. 10° W. and is parallel to the great line of fracture already mentioned.

Roach Bridge near Preston.—The River Darwen has open out along its banks a fine section in light red and yellowish sandstones with a base of marly conglomerate which seems to resemble the beds of the Lower Keuper Sandstone more than those of any other formation with which I am acquainted.† They rest unconformably on dark fossiliferous shales belonging to the Yoredale series, which dip to the south at 50°, while the beds of the newer formation dip gently to the westward. Whatever may be the exact age of the latter, it is clear that the Carboniferous rocks have here been subjected to a large amount of denudation before the newer beds were deposited upon their upturned edges.

Having arrived at the northern limit of our survey on the west side of England we must now retrace our steps into the Midland counties.

East Warwickshire.—This subdivision forms the base of the Trias over a large tract of this part of the country, the Bunter Sandstone having disappeared in the neighbourhood of Coventry, Leamington, and Warwick. The formation, however, has fully compensated for its dwarfish development by the richness of its organic remains, for it has yielded fragments of upper and lower jaws, vertebræ, ribs, &c., which have been referred by Professor Owen to five species of reptiles, and induced the late Dr. Buckland to refer the beds to the lower division of the Keuper series.‡ From the same beds at Cubbington Professor Huxley has also described the left branch of the lower jaw bone of *Labyrinthodon Jaegeri*, which was found by Mr. Richard Gibbs, collector of fossils for the Survey.§ The formation has also been described by Sir Roderick Murchison and Mr. Strickland many years since, and more recently by

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* At Scarisbrick Park deep borings in search of coal have been made (it need scarcely be said) without success.

† Mr. E. W. Binney, F.R.S., who was the first to describe this section, refers the beds to the Permian formation.

‡ "Geological Transactions," 2nd series, vol. vi.

§ "The Geology of the Warwickshire Coal-field," by H. H. Howell, F.G.S., Appendix 2, p. 56. It appears the original specimens collected by Dr. Buckland are lost.—"Geol. Trans.," 2nd series, vol. v., 1837.

Mr. Howell of the Geological Survey, who has shown the relationship of these beds to the underlying strata of red sandstones, marls, and conglomerates of Coventry which are now known to be of Permian age.*

The Lower Keuper Sandstone in this district generally consists of white, red, and brown sandstones with intercalated reddish marls, the basement beds being sometimes (as at Hammerwich) slightly conglomeratic and calcareous, the whole thickness as determined at Sutton Coldfield is 200 feet.

In the neighbourhood of Litchfield these beds are well developed, and owing to their horizontality are spread over a large tract of country. They are well exposed to view at the village of Stowe, and in the cutting of the South Staffordshire Railway. A small tract is described by Mr. Howell as occurring at New Barr, two miles south of Litchfield, surrounded on all sides, apparently, by faults which depress the Keuper beds to the same level with the Bunter Sandstone.

The Lower Keuper Sandstone forms a nearly continuous belt around the area of Carboniferous and Permian beds of East Warwickshire, and wherever prevented from appearing, it is owing to the existence of faults which bring down the Red Marl against the older formations. At Tamworth the lower beds are formed of calcareous breccia, or conglomerate, which is shown in old quarries near the Two Gates and at Bole Hall. Owing to the presence of the fault which ranges in a southerly direction by Dosthill and Kingsbury to Berkswell, the beds of this subdivision are concealed as far as the village of Maxtoke, where they reappear, and may be traced southward to Berkeswell and the Birmingham Railway when they are again faulted against the Permian beds. About a mile north of Kenilworth Castle they reappear, rising from beneath the Red Marl.

Along the eastern side of the Permian and Carboniferous area, these beds form a narrow strip which may be traced from Warwick northward to Nuneaton by Leamington, Berkenhall, and Wyken. At Marston Jabet a fine section is laid open in a quarry showing horizontal beds of red marl, white sandstone, and conglomerate, resting on inclined beds of lower Coal-measures and intrusive greenstone, dipping east at an angle of 15°.† At Wyken Colliery the unconformable superposition of the Keuper series, both to the Permian and Carboniferous rocks, was determined in the sinking of the pits; for after passing through a series of white sandstones and red marls 75 feet thick, and lying in a nearly horizontal position, red sandstones with purple marls dipping westward at a considerable angle corresponding to that of the underlying Coal-measures (21°) were found.‡

In the neighbourhood of Warwick the sandstone has been extensively quarried for building purposes, as also at Leek Wootton, Emscote, and Cubbington Heath. The upper beds are often rippled, and pass gradually into the overlying Red Marl series.

The Upper Keuper Sandstone, consisting of white and greyish fine-grained micaceous sandstone with bands of greenish marl is occasionally well developed at intervals in the Red Marl series. These beds with reptillian footprints were described by Sir R. Murchison and Mr. Strickland in 1837 as occurring at Shrewley Common, overlying a

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* "Geology of the Warwickshire Coal-field," p. 37.

† This section is shown in Mr. Howell's Memoir by a woodcut from a sketch taken by Professor Ramsay (Fig. 4, p. 39).

‡ Ibid., p. 40.

thick series of red marls, and affording at the entrance to the tunnel of the Birmingham canal the following section:—*

Red marl - - -	30 to 40 feet.
Sandstone and green marl -	20 feet.
Red marl - - -	10 „
	70 „

At Burg (or Burge) Hill, south of Warwick, these observers discovered an Ichthyodorulite of the genus *Hybodus*, and examples of *Posidonia* (*Estheria*) *minuta*.† These beds are finely developed at Henley-in-Arden, where they lie about 250 feet below the Lias and about 350 feet above the base of the Red Marl, which gives about 600 feet for the thickness of this formation.‡ Sections may also be seen at Mouse Hill near Tamworth, Lapworth Hill, Rowington, Wroxhall, and Pinley Hill near Claverdon. Both at Preston Bagot and Rowington, the Rev. P. B. Brodie has found large footprints of Labyrinthodon, the specimens of which he has presented to the Warwick Museum, which contains the finest collections of Triassic remains in the kingdom. I must refer the reader to the list of these fossils which has been most kindly drawn up for this Memoir by that gentleman (*see* Appendix A).

Ashby-de-la-Zouch.—The Lower Keuper Sandstone which surrounds and rests in isolated patches on portions of the Leicestershire Coal-field attains an average thickness of 150 feet.§

As already remarked the neighbourhood of Ashby is the easterly limit of the Bunter Sandstone. It will be seen on referring to the maps of the Geological Survey ‖ that the Conglomerate beds terminate along a north-east line passing diagonally through the centre of the coal-field; consequently the Keuper sandstones and marls rest on Bunter Sandstone on the western and northern flanks of the coal field, and directly on the Coal-measures and other Palæozoic rocks on the eastern and southern sides.

This distribution of the formations is probably due in some degree to unconformity, for it is to be recollected that a wide gap in time elapsed between the deposition of the conglomerate of the Bunter and the basement beds of the Keuper, partly filled in England by the period of the Upper Mottled Sandstone, and on the continent by the Muschelkalk; and during this period oscillations of the land and sea bed occurred, to which reference will be made more fully in treating of the physical geography of the Trias.¶ These changes may have produced a slight unconformity, and the denudation, to a certain extent, of the Bunter Sandstone in Leicestershire and Warwickshire; but it is also certain that this division of the Trias becomes attenuated and actually disappears in these counties, having apparently never extended further towards the south-east of England.

The base of the Lower Keuper Sandstone from the Trent, and round by the flanks of Charnwood Forest to Burton-on-Trent, is usually a band of red clay or marl, containing near Ashby nodules of earthy hæmatite. Upon this we find, as at Castle Donnington and Coalville,

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* Trans. Geol. Soc., 2nd series, vol. v., p. 336. The reptillian footprints are figured in plate 28, fig. 1.

† Figured in plate 28.

‡ "Geology of the Warwickshire Coal-field," p. 42.

§ See Horizontal Section, Sheet 52.

‖ Sheets 63 S.W., 71 N.W.

¶ This view of unconformity is supported by the opinion of the late Rev. W. H. Coleman, of Ashby.

a bed of quartzose gravel, becoming a breccia of slate and porphyry upon its approach towards the borders of the Cambrian rocks of the Forest which formed the coast-line of the period. The superior beds generally consist of white sandstones, interstratified with red shales, through which several coal-shafts penetrate in the district of Coleorton.* In this neighbourhood a fine section is exposed to view in the cutting of the colliery railway, at the incline where it ascends from the Coal-measures through the escarpment of the Lower Keuper Sandstone into the Red Marl.

In the quarry at Weston Cliff, suncracks, ripple-markings, and worm-tracts may frequently be observed, and foot-prints of *Labyrinthodon* have been noticed by the late Mr. Marcus Huish, of Castle Donnington. Traces of this reptile have also been found in these beds near Burton.

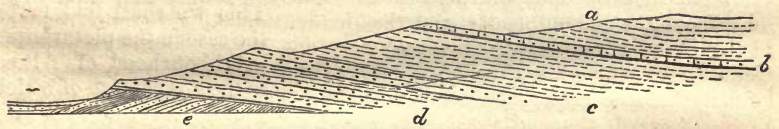
The passage of this subdivision upwards into the Red Marl is very gradual in the Coleorton district, as may be seen by reference to the vertical sections of Bagworth and Ibstock collieries, proving the intimate connexion of the two series of beds. At Castle Donnington and south of Donnisthorpe the Upper Keuper Sandstone occurs in a position about 60 or 100 feet from the base of the Red Marl. At Kegworth, however, the interval is only about 25 feet. It consists of one or more beds of very fine-grained white and grey sandy mudstone, with ripple-marks, occupying, in all probability, different geological horizons.

Except along the west side of the coal-field, these strata are but very slightly disturbed. Everywhere else they seldom have a dip of more than four or five degrees. The great dislocations which are so numerous in the coal-field have unquestionably been produced previous to the deposition of the Triassic series, and consequently the Keuper beds are generally to be found tranquilly reposing on the tilted and denuded edges of the Carboniferous rocks.†

The absence of the Bunter Sandstone at Castle Donnington is proved by the occurrence of shales and grits, probably of the Millstone series, immediately below the Lower Keuper Sandstone. A section in these beds occurs along the base of the cliff, which forms the boundary to the alluvial plain of the Trent. The succession of beds may be easily ascertained by numerous sections about the town, and is shown in the following woodcut:—

Fig. 47.

Section at Castle Donnington, Derbyshire.



~ Alluvium of the Trent. *e.* Millstone Grit series. *d.* Lower Keuper Sandstone.
c. Red Marl. *b.* Upper Keuper Sandstone. *a.* Red Marl.

A fault with a downthrow on the north side enters under the alluvium of the Trent at the base of the hill on which Donnington is built. Its

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* See Vertical Sections, Sheet 21.

† It is not my intention to describe the Red Marl, with its included Upper Keuper Sandstones, in this part of the country; but I may again refer to the excellent paper of Mr. Plant on the remains afforded by these beds at Leicester, consisting of bones and teeth of Placoid fishes, annelide tracks, and *Estheria minuta*.—Geol. Journ., vol. xii.

position may be ascertained in a lane section near the church, where the strata are highly disturbed.

The banks along the northern slope of Donnington Park also afford good sections, which are beautifully diversified by luxuriant vegetation, and some fine old forest trees.

North Staffordshire.—Near Stone several good sections occur, especially that seen on the railway north of the town. The beds consist of soft white and yellow sandstone, with marly interstratifications, and are here thrown down by an east and west fault against the Permian formation. The new road leading to Moddershall Mill also exhibits these beds in many places, but they are not capable of affording good building material. Quarries have been opened at Pitts Monument in Sandon Park, at Weston Bank, Tixall, and Brocton. In these, the rock is for the most part of a light brown colour, but at Colton and Rugeley the same beds yield a white freestone which affords a handsome building stone. Quarries have also been opened at Fulford, Blithe Marsh, and Cresswell. Near Cresswell Mill a boring was made in 1856 in search of coal, but was abandoned at a depth of 600 feet, before the New Red Sandstone was pierced through. The locality is probably not badly selected with reference to the lie of the Coal-measures, as far as can be inferred from the position occupied by the coal-beds in the Cheadle basin. Had the New Red Sandstone been penetrated, it is probable no Permian or Upper Coal-measures would have been encountered.*

There are two sections in the neighbourhood of the Potteries interesting as being the last places to the eastward where we find the Lower Keuper Sandstone resting upon the soft variegated sands of the uppermost division of the Bunter. One of these sections occurs in the railway cutting on the east side of the Longton tunnel; the other in the Cookshill road near Caverswall. We have here reached the easterly limit of the Upper Mottled Sandstone, and henceforward the beds of the Keuper series rest directly on the Conglomerates of the Bunter. This we shall find to be the case in the picturesque neighbourhood of Alton, to the description of which I now proceed.

Fig. 48.

PEAKSTONES ROCK, ALTON, STAFFORDSHIRE.

* Mr. Wynne, H.M. Inspector of Mines, informs me that the boring was abandoned shortly after the Conglomerate Beds were reached, and that the greater part of the sections was through soft variegated sandstone, belonging probably to the upper subdivision of the Bunter. The section here would therefore be as follows :—

	Yards.
1. Red Marl	25
2. Lower Keuper Sandstone	50
3. Upper Mottled Sandstone	100
4. Conglomerate Beds	120
Total	195 or 200.

Alton District.—As it is the province of the anatomist to discover the relationship between the outward form of an animal and its skeleton, so I apprehend it belongs to one who undertakes to write the geological structure of a district to point out the dependence of its physical features upon the composition and arrangement of its rocks.

This dependence has already been touched upon when treating of the Triassic rocks in several districts where the physical features are most strongly pronounced, as in the ranges of Bridgenorth, Hawkstone, Peckforton, and Delamere Forest. In none of these, however, are the combinations of escarpment, rocky cliff, and deep ravine, decorated and enriched by vegetation and works of art, more profusely put forth than in the vicinity of Alton Towers.

I can scarcely trust myself to describe, even in strictly geological phrascology, the landscape features of this lovely spot—this English vale of Tempe—so enchanting does it seem, even when looking back upon it through the vista of years. Yet, whoever has studied its geological structure cannot, I think, fail to allow that, notwithstanding the profuse expenditure of decorative art, it is the physical features which give this district its highest interest.

The Triassic rocks of this part of Staffordshire mantle round the southern flanks of the loftier Carboniferous district, of which Weaver Hill forms the culminating elevation. The steep-sided, bare, and smooth flanks of this upland range of Mountain Limestone form a striking contrast to the diversified and richly wooded tract of New Red Sandstone which slopes down towards the south. This latter tract consists of a series of escarpments, divided from each other by narrow and deep dells or ravines, with wooded banks, and crested generally by a cliff of hard white conglomerate, which often appears towering above the tops of the trees, itself treeless. This conglomerate (thus forming the edge of the escarpments) is the basement bed of the Keuper series, the very same rock which occupies a similar position in the Peckforton Hills. Here, however, it rests on the softer sandstones of the Conglomerate subdivision of the Bunter, instead of the Upper Mottled Sandstone, which is absent in this part of the country.

This conglomerate base of the Keuper resembles that at Claverley in Shropshire, with the exception that the cementing matter is silica instead of carbonate of lime.

The pebbles are in the great majority of cases similar to those of the underlying Conglomerate beds of the Bunter Sandstone, being formed of white and coloured quartz-rock, well rounded ; and if any fragments of Carboniferous rocks occur, they are extremely rare. This is the more remarkable as the Triassic formation seems in some places near Ashbourn to have been deposited around the flanks of the Carboniferous uplands.

The thickness of the Lower Keuper Sandstone is here about 200 feet. The dividing line is generally a thin band of Red Marl, upon which is superimposed the white conglomerate, about 40 feet in thickness, which passes upwards into white freestones with bands of marl. These are surmounted by the thin laminated sandstones which introduce the Red Marl series. The district is traversed by several faults ranging

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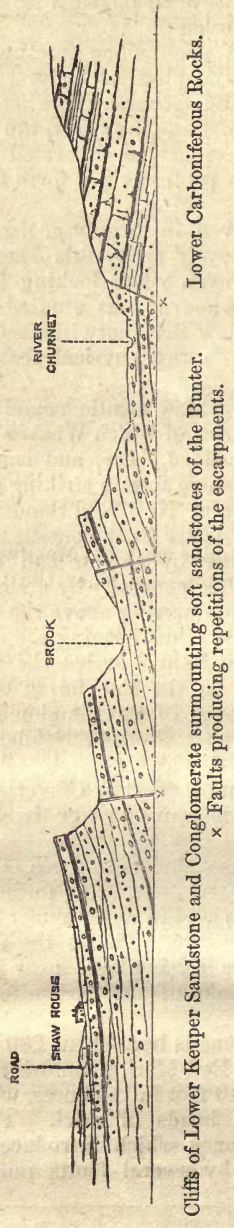
Another boring has been made near Weston Hall, Caverswell, but the bottom of the New Red Sandstone was not reached at 450 feet. It is probable the boring was commenced on the down-cast side of the fault which traverses this district from north to south. I am indebted to Mr. Goddard, C.E., for this and other points of information. For the actual thickness of the New Red Sandstone in this district, see Horizontal Section, Sheet 57.

east and west, and producing repetitions of the conglomerate escarpment. These are represented in one of the Horizontal Sections of the Geological Survey,* and on a smaller scale in the annexed woodcut.

Fig. 49.

SECTION NEAR ALTON, SHOWING THE SUCCESSION OF THE ESCARPMENTS.



Cliffs of Lower Keuper Sandstone and Conglomerate surmounting soft sandstones of the Bunter.
× Faults producing repetitions of the escarpments.

Near Wootton Grange one of these faults becomes metalliferous, and was formerly worked. In the vein-stone I found traces of galena, and the carbonates and sulphurets of copper. From Ramshor to Okeover the beds of Keuper series appear to rest directly on the flanks of the Carboniferous rocks, which once, in all probability, formed a shelving shore, along which the Triassic beds were deposited during the progress of submergence. The relative position of the Triassic and Carboniferous rocks in this district goes to confirm the opinion I have for some time held, that the elevation of the latter along the southern slopes of the Derbyshire Limestone country took place at the close of the Carboniferous period.

Several large quarries have been opened in the Lower Keuper Sandstone of this neighbourhood, the principal of which are at Hollington, Crumpwood near Alton, and Stanton. These yield a white freestone of good quality, and capable of being worked in large blocks. The stone of Hollington quarry was very favourably noticed by the Commissioners appointed to report upon a building material suitable for the new Houses of Parliament. Alton Towers is built of freestone obtained from a quarry less than half a mile east from the site itself.

Proceeding eastward, and having crossed the Dove, we find the Lower Keuper Sandstone thinning away in a rapid and very unusual manner, till at length at Brailsford it disappears altogether. The Red Marl formation here rests immediately upon the Bunter Conglomerate, as may be very satisfactorily ascertained from evidence afforded in the outskirts of the village. The base of the Waterstones is here a bed of marl, of which bricks are made opposite Ednaston Lodge. This is succeeded by a few beds of brown sandstone, shown at Shirley; and as far as I have been able to ascertain the superposition of the marl on the conglomerate is attributable to the absence of the sandstones, the two beds of marl being thus brought together and thrown into one.

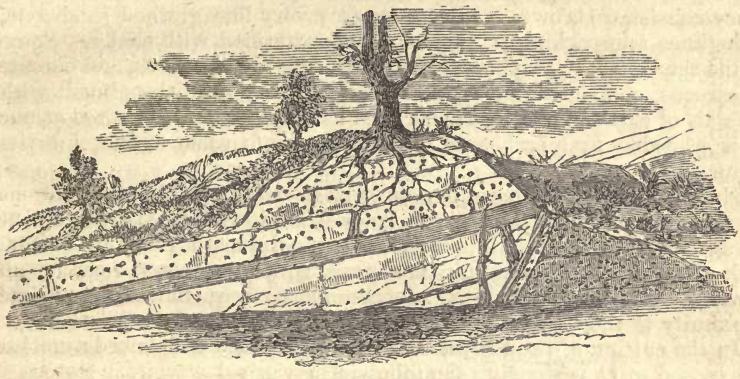
A fault of unusual length occurs in this country. Commencing at some point near Cheadle it ranges eastward, and after traversing the New Red Sandstone for a distance of 17 miles,

* No. 2, Sheet 57.

with a downcast on the north side, we lose sight of it in the Red Marls near Derby. Throughout its course it sends off occasional branches, the number of which amounts to six at least. This fault has been beautifully opened to view in the cutting of the Alton and Oakamoor road, about 200 yards east of the smelting mill, and is represented in the adjoined sketch (fig. 50).

Fig. 50.

Sketch of large Fault between Alton and Oakamoor.



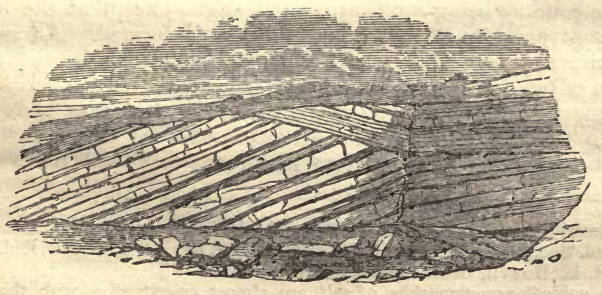
It is again exposed to view in a lane half a mile west of Mackworth, where it causes a downthrow of the Waterstones against the Coal-measures.

Over the line of country extending from the Potteries towards Ashbourn, nearly all the New Red Sandstone faults have a normal direction of about W. 10 N. At Kirk Langley, in a large quarry, the basement marl of this subdivision is seen reposing unconformably on the variegated flagstones and shales of the Millstone Grit. Notwithstanding the hard texture of the grit, the line of junction is very even. The dip of the grit is north at 9°, that of the superimposed marl, south at 4°. The thickness of the Lower Keuper Sandstone at Ashbourn and Derby seldom exceeds 30 feet.

Fig. 51.

Sketch at Kirk Langley, Derbyshire.

Showing the Keuper Marls and Sandstones resting unconformably on the Millstone Grit series.



The Upper Keuper Sandstone assumes at Derby and Nottingham an unusual importance. In Gloucestershire this arenaceous band divides

the Red Marl into two nearly equal divisions. On tracing it northward into Warwickshire and Leicestershire we find it gradually approaching the base of the Red Marl,* and in the counties of Derby and Notts the Upper and Lower Keuper Sandstones are in close proximity. It is probable, however, these beds do not represent the same geological horizon, but appear at intervals in positions differing from each other in stratigraphical position.

The Upper Keuper Sandstone is very well developed in the neighbourhood of Chilwell near Derby. West of the village a quarry has been opened showing a face of 18 feet in depth cut through these beds. They consist of brown, white, and grey very fine grained sandstone, sometimes approaching a mudstone, interstratified with shales. Some of the sandstones are ripple-marked, occasionally micaceous, and become calcareous and ferruginous along the joints. Vesicles lined with crystals of carbonate of lime occur, and as the rock burns to a red colour it is probable that carbonate of iron enters, to some extent, into its composition.

Near the village there are two large brick-yards in which fine sections in the marl have been opened. Its position is underneath the Upper Keuper Sandstone; and interstratified with the marls there are several beds of bluish shale and thin mudstone, which are very common all through the formation, but become more frequent in immediate proximity to the Upper Keuper Sandstone.

In the cutting of the Erewash valley railway near Stapleford a section is exposed to view showing the following series:—

	Ft.	In.
1. Red Marl (several feet in thickness).		
2. White and light-blue hard mudstone - - -	1	2
3. Bluish shales and sandstones - - -	6	0
4. Red Marl (thickness unknown).		

On the hill above Sandiacre the marls are worked for the manufacture of bricks and tiles. The beds are immediately above the Upper Keuper Sandstone, and have frequent interstratifications of blue shale. These latter are remarkable for containing numerous pseudomorphous crystals of common salt. A small slab from that locality now before me is full of them, some of the crystals being imbedded in each other. The late Mr. Strickland noticed these pseudomorphs in the Keuper Sandstone of Gloucestershire. A specimen has been shown me from the neighbourhood of Liverpool, and I have observed them at Croxden, Staffordshire, Cheshire, and Lancashire, and in the same beds at the new cemetery near Derby.†

Between Chilwell and Derby the Upper Keuper Sandstone rises into rather high ridges, cropping out along the north side of the summit, the dip of the country being south at a small angle, except at the bank of the Derwent opposite Derby, where a basin is formed. An east and west fault, ranging from Chaddesden to near Sandiacre, causes a repetition of the outcrop of the Keuper Sandstone.

An almost continuous section from the Conglomerate beds of the Bunter to the Upper Keuper Sandstone is afforded on ascending the hill by the lane which leads from Sandiacre to Cloud Hill. I have

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* For descriptions of these beds in Warwickshire, see papers by Mr. Plant, Quart. Journ. Geol. Soc., vol. xii., p. 369; in Leicestershire, Rev. P. B. Brodie, ibid. p. 374; also Mr. H. H. Howell, Geol. Warwickshire Coal-field.

† These cubical pseudomorphs of salt are almost co-extensive with the Keuper formation. I am informed by Mr. Warrington Smyth that they are common in Germany, and Mr. Ormerod has observed them in Devonshire.

presented a copy of this section for the purpose of showing the proximity of the Upper and Lower Keuper Sandstone in this country.

Section at Sandiacre.

		Ft.
Red Marl series	*c.* Red and grey marls	50
	b. Upper Keuper Sandstone	10
	a. Red and bluish shaley marl, with a thin band of sandstone	50
Lower Keuper Sandstone	Brownish evenly bedded sandstones and shales	40
Conglomerate beds (*Bunter*)	White and light red sandstone and conglomerate - thickness about	100

In excavating for the new cemetery large quantities of the "skerry stone"* were brought to the surface. The beds consist of white mudstone and fine micaceous sandstones, the latter highly laminated and full of ripple marks. Mammilar balls, often twisted and curved so as, when jutting out of a piece of rock, to appear like portions of Nautali, are common ; they are, however, merely concretionary or concentric nodules.

Nottingham.—As the Upper Mottled Sandstone is entirely absent the Lower Keuper Sandstone rests immediately upon the Pebble beds of the Bunter. The former is exposed to view in numerous fine sections east and north of the town, where nearly the whole series is repeated by a north-westerly fault. Along a new road leading to Mapperly Hill an almost continuous section is presented for the distance of a mile, which is, however, unfortunately interrupted at the point where the fault to which I have referred may be supposed to pass. The base of the series is generally a bed of red shale several feet thick, which is overlaid by about 100 feet of regularly bedded white and brown sandstone, ripple-marked, and largely interstratified with red and grey shales. Upon these, with an evident passage, there rests a series of red marls or shales containing several beds of white and blueish fine-grained sandstone at regular intervals down to the base. In the section referred to we find, on descending towards Nottingham, no less than a dozen beds of Upper Keuper Sandstone, varying from one to two feet in thickness, in the first 150 feet of the Red Marl ; but the highest bed is generally the thickest, and caps the top of the high grounds north and east of Nottingham. It is evident that in this and adjoining counties the Upper Keuper Sandstone is not confined to one horizon, but consists of several beds which thicken out in different localities. Gypsum, in thin beds, is largely distributed throughout the Keuper series.

In a lane near Highfield House, Lenton, beds of Upper Keuper Sandstone may be seen thrown down by a fault against the Lower Mottled Sandstone. This fault is a continuation of that which bounds the Coal-measures along the north side of Bramcote Hill.† It has

* This is the local term for the lands of Upper Keuper Sandstone, and is clearly of Celtic derivation (*carrig*, a rock).

† At this point we have the data for calculating the amount of the displacement. The Keuper Sandstone seen in the section is in all probability the bed at 150 feet from the base of the Red Marl, which is brought in contact with the Lower Mottled Sandstone at about the centre of its thickness. Taking the subdivisions at the following approximate thickness, the amount of *throw* would be as follows:—

		Feet
Keuper	Red Marl	150
	Lower Keuper Sandstone	100
Bunter	Conglomerate beds	250
	Lower Mottled Sandstone	50
		550

recently been proved to range under the alluvial plain of the Trent, close to the spot where Sir R. Clifton's new colliery is being sunk.

To the north of Nottingham the Lower Keuper Sandstone takes a north-easterly direction by Arnold, Oxton, and Farnsfield, following the flanks of a range of hills, capped by the Red Marl, and called "The Plains," the upper surface being remarkably level, owing to the horizontal position of the strata. From the section levelled across this country by Mr. Aveline (Sheet 61), it appears that the Lower Keuper Sandstone attains a thickness of about 120 feet. In the laminated sandstones, annelide tracks, suncracks, and rain-pits have been observed by Mr. Tarbotton, F.G.S. An excellent section is laid open in the sides of the Mansfield road at Red Hill, about five miles north of Nottingham, showing a series of interbedded laminated brown sandstones and red marls.

The Keuper series follows in regular succession the Conglomerate beds of the Bunter northward from Nottingham to the alluvial plain of the Humber, passing along the east of the more elevated tracts of Sherwood Forest by Ollerton, Garnston, and Retford. Over the forest lands the ground gradually slopes to the eastward in the direction of the dip from an elevation of 300 to 640 feet above the sea, interrupted only by minor undulations. "On crossing the upper and eastern boun-" dary of the Pebble beds we leave the sandy forest lands, and come " upon a rich soil and cultivated country, and begin to ascend the high " ground capped by the Keuper Marls. These hills, of soft red marl, " vary in height between 200 and 300 feet above the sea level, having " their steeper slopes to the west, and their gentler inclinations to the " east; but these latter are much cut up by numerous small valleys, the " brooks in which chiefly rise near the top of the hills, and flow " eastward."*

Throughout this district the Lower Keuper Sandstone rests directly upon the Pebble beds, and is introduced by blueish clays and light-coloured sandstones. These are succeeded by soft porous sandstones, sometimes white, but generally of brown, reddish-brown, or grey colours, interstratified with red marl, sometimes sandy. These beds pass upwards by gradations into the Red Marl series, which also contains numerous bands of fine greyish sandstone, and bands or veins of gypsum. In fact, there is here, as in many other places, no definite boundary between the two members of the Keuper series.

About two miles north of Retford the trend of these Upper Triassic beds takes a north-easterly direction for some distance, but they are again thrown to the westward by a large fault which crosses the Chesterfield canal at the north end of the Drakehole tunnel; and here the Keuper Marls with white sandstones are brought down against the Pebble beds of the Bunter, the downthrow of the fault being on the north side.†

The basement beds of the Keuper, in the form of bluish clay, may be seen at Everton; but north of this town the sections are obscure.

A mile farther east the same fault brings the lowest beds of the Red Marl against a certain depth of conglomerate, and here the throw would be about 300 feet, which shows that the throw is decreasing westward at the rate of 200 feet per mile.

* Mr. Aveline, "Geology of Parts of Notts and Derbyshire," p. 15.

† "Geology of Parts of Notts and Yorkshire, &c.," p. 18.

CHAPTER IX.

The New Red Marl and Rhætic or Penarth Beds.

Though not falling in with the original scope of this Memoir it might be considered incomplete if I did not here devote a special chapter to this upper member of the Triassic series, which forms so important a feature on the Geological Map of the Central counties, and covers even a larger extent of country than the Permian and Bunter sandstone combined.

Distribution.—Commencing on the coast of Devonshire, the formation stretches northward along the base of the Malvern and Abberley Hills, being overlaid by the Rhætic or Penarth beds,* and the Lias, which generally commence along the line of a slight ridge or minor escarpment. Over this district the beds were originally described by the late Mr. H. E. Strickland, and Sir R. I. Murchison, who also traced the range of a band of fine sandstone, which occupies a central position in the series, and is accompanied by shales with *Estheria minuta*, and pseudomorphous crystals of common salt (chloride of sodium).† The area described in this Memoir ranges from Gloucester northwards. One of the finest sections in this district is that of Garden cliff, near Gloucester, showing the junction of the Keuper marls with the Rhætic series, and this again with the Lias, and described by Dr. Wright under the name of the "*Avicula contorta* beds." In a still lower horizon there is a very fine opening out of the Red Marls at the Worcester Railway Station, near the entrance to the tunnel, which will serve to illustrate the general character of the beds over the whole district.

In Warwickshire and Leicestershire this formation occupies large tracts of undulating country; and as the Bunter Sandstone is here very thin or entirely absent, the Red Marl with the subordinate Lower Keuper Sandstone encloses the Palæozoic formations of Permian, Carboniferous, and Cambrian ages, filling in the old valleys and hollows of the Charnwood Forest rocks, which were apparently unsubmerged during the greater part of this stage. To the eastward, the Lower Lias forms the natural boundary, stretching along a slightly indented line from the neighbourhood of Stratford-on-Avon to the banks of the Humber at its junction with the Trent.

Along the southern margin of the Carboniferous tract of Nottingham and Derbyshire, the Red Marl in company with the Lower Keuper Sandstone sometimes rests directly upon the Palæozoic beds, and near Ashbourn completely encloses a boss of Carboniferous Limestone. Further westward, however, on approaching the Potteries, the Bunter Sandstone augments in thickness and importance, and the Red Marl of this tract is completely dissevered from the great tract of Central Cheshire and North-east Shropshire by the uprising, in the form of a low and broken arch, of the Permian and Bunter Sandstone series.

In Salop and Cheshire the Red Marl occupies an area of about 480 square miles, lying encased in an oval ring of New Red Sandstone, which, owing to a large fault, disappears at one part of the eastern margin at the foot of Congleton Edge, where the Keuper marls are thrown down against the Carboniferous rocks. The southern limits of this

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* So called by Mr. Bristow, F.R.S., of the Geological Survey, in consequence of the fine sections these beds display near Penarth on the Bristol Channel. See Brit. Assoc. Report, 1864 (Bath). See p. 104.

† Geological Transactions, 2nd series, vol. v. (1837).

tract extend to the northern flanks of Grinshill and the Hawkstone Hills, and the northern to Timperley, Warburton, and Lymm. The western margin extends to the flanks of the Frodsham, Delamere, Peckforton, and Malpas Hills. As these ranges have already been fully described, no further reference will here be needed. Near the southern extremity of this tract there is a large outlier of Lower and Middle Lias, at Prees and Whitchurch.*

Small outliers occur in the promontory of Wirral, and at Southport, on the western coast of Lancashire; these beds have been bored to a depth of 207 feet, and were found to contain gypsum and common salt.

Mineral Characters, and Beds of Rock-salt.—The mineral characters of this series are remarkably persistent throughout the whole of its range from the shore of the Bristol Channel to the estuaries of the Mersey on the one side of the island, and of the Humber on the other. It consists of a series of bright red marls and shales, with intercalated bands of greyish sandy and micaceous shales, or thin bands of very fine-grained sandstone (Upper Keuper Sandstone). Towards its base it becomes rather more sandy, and passes downwards by frequent interstratifications of brown laminated sandstones into the underlying subdivision of the Lower Keuper Sandstone. In Cheshire the Red Marl becomes rather more shaley than in the Midland counties, from the larger intermixture of sandy sediment; and throughout the whole of its range irregular bands of gypsum occur at intervals, sometimes of considerable thickness, as at Chellaston near Derby, where it has been worked for hundreds of years by mining from the outcrop. Brine springs and beds of rock-salt have been found in several parts of the country, especially at Droitwich and Stoke in Worcestershire, at Northwich, Winsford, Dunham, Anderton, Moulton, Middlewich, Wheelock, Roughwood, Lawton, Baddiley, Dirtwich, Audlem, and Nantwich in Cheshire; and at Shirleywich in Staffordshire. Elaborate descriptions of the mode of occurrence, and process of extracting the salt of commerce in Worcestershire, have been recorded by Mr. Leonard Horner,† and in Cheshire by Mr. Henry Holland.‡ At Droitwich the salt has been extracted from the brine for upwards of 1,000 years, as it was one of the sources of revenue granted to Worcester Cathedral by Kenulph, King of the Mercians, in the year 816. From the account furnished by Nash in his "History of Worcester," and quoted by Mr. Leonard Horner, it appears that the brine occurs in a sort of subterranean reservoir proved in several borings to be about 22 inches in depth, with a floor of rock-salt, and a roof of gypsum from 40 to upwards of 100 feet in thickness. When this is pierced by boring, the brine ascends to the surface with force; above the stratum of gypsum there occurs a varying thickness of red marl. It is only at Northwich that the salt is mined by pits sunk into the beds of rock-salt. Here there are two separate beds, the upper one of which was discovered about the year 1680 at Marbury when sinking in search of coal. It is inferior in thickness and quality to the lower bed, which was subsequently discovered towards the end of the last century, and which is separated from the upper by beds of indurated clay and fine-grained sandstone with bands of rock-salt. The following section was furnished to the author in 1864 by Mr. J. Thompson of Northwich,

* First described by Sir R. Murchison in the *Silurian System.*

† Trans. Geol. Soc., 1st series, vol. ii., p. 94.

‡ Ibid., vol. i., p. 38. See also Mr. G. W. Ormerod "On the Geological Features of "the Salt Field of Cheshire, &c.," Journ. Geol. Soc., vol. iv., p. 262, wherein the author endeavours to trace the range of lines of dislocation according to the different levels at which the beds of rock-salt have been proved.

and will serve to give a general idea of the thickness and position of the beds:—

Sections of the Rock-salt and accompanying Strata at Northwich.

The Island Salt Works.

	Feet.
1. Quick-sand	8
2. Red marl ("metal")	90
3. First salt-rock	75
4. Indurated red clay, &c.	30
5. Second salt-rock	75
6. Shale or marl ("metal") with thin bands of salt-rock from a few inches to seven feet in thickness	180

Marston Mine.

	Feet.
1. Boulder clay, &c.	144
2. Red marl	
3. First salt-rock	75–84
4. Indurated clay	30
5. Second or great salt-rock bed	96

Mr. Ormerod states that the thickness of the upper beds of salt-rock varies from 84 to 90 feet in pits sunk on the north-west side of Northwich, decreasing eastward to 81 feet. It thins off towards the south-west, losing 15 feet in the course of a mile. The higher portions of the lower bed are not worked, but underneath there is a purer stratum of 12 or 15 feet in thickness, from which the salt is extracted by mining. The thickness of this lower bed has been proved by Mr. Nieuman at the Marston mine to be 96 feet in thickness, while at other places it has been penetrated to a depth of 117 feet without reaching the bottom.

The salt-rock occurs in a highly crystalline form, generally translucent, with a slight tinge of yellow or red from the intermixture of minute quantities of clay and peroxide of iron. The form of the crystal is a cube, and in some places beautifully perfect colourless crystals of very pure chloride of sodium may be obtained. There are also small proportions of other salts, as will be seen by the following analysis by Mr. Henry of specimens from this district, as given in Bristow's "Glossary of Mineralogy."

Chloride of sodium	98·32
Sulphate of lime	0·65
Chloride of magnesium	0·02
Chloride of calcium	0·01
Insoluble matter	1·00
	100·00

The actual limits of the beds of salt are not very accurately known; but there seems to be considerable force in the view, originating I believe with Mr. Ormerod, that the meres or little lakes of Cheshire may owe their origin to the local subsidence of the ground, consequent on the abstraction of the rock-salt, at present or formerly existing under these spots, by dissolving into brine which is being constantly carried away by drainage at intervals over the whole area of the red marl.*

The persistency of beds of rock-salt wherever this formation extends is exemplified by the brine springs of Cheltenham, which ascend through the overlying Lias, as originally explained by Sir Roderick Murchison,† and by borings put down at Rugby from the Lias into the Red Marl in search of fresh water to a depth of 1,141 feet from the surface, and 663

* The position of the beds of salt is shown in the horizontal section of the Geological Survey, sheet 64.

† "Geology of Cheltenham."

feet below the Lias. Professor Ramsay has suggested to me that when the salt is absent, it is owing to gradual waste through dissolution in the form of brine; but when, owing to the geological structure of the beds, the escape of brine is impossible by a natural process, the rock-salt is then locked up and remains intact. The fact that the outcrop of any of the salt beds either in Worcestershire, Cheshire, or Staffordshire is unknown, seems capable of being accounted for on the above ground. As Sir Charles Lyell well remarks, these brine springs are known to have flowed for more than 1,000 years, and the quantity of salt which they have carried into the Severn and Mersey must be enormous.*

Chemical Composition.—The Red Marl forms excellent agricultural land, being rich in a variety of products, and over large tracts of the Central counties was formerly dug out for "top dressing" or manuring the ground. It probably varies considerably in composition in different localities, but the following analysis by Dr. A. Voelcker will probably be considered as representative of the composition of the central portion of the formation. The specimen was taken from the railway cutting at Worcester Station. It will be observed that there is an analysis of both the red and grey portions.†

	Analysis.			
	Red.			Grey.
Water of combination	4·45			3·71
Protoxide of iron	1·60			1·77
Sesquioxide of iron	2·41			0·80
Bisulphide of iron	0·059			0·029
Alumina	11·14			12·77
Lime	4·85			3·71
Magnesia	3·06			2·17
Potash	0·69			0·71
Soda	traces			0·02
Sulphuric acid and loss	3·311			4·741
Matter insoluble in hydrochloric acid :—				
Alumina	9·39		11·72	
Silica	53·62		53·40	
Oxides of iron	0·78	68·34	0·99	69·49
Lime	0·64		0·61	
Magnesia	1·69		1·11	
Alkalies and loss	2·22		1·66	
	100·00			100·00

Phosphoric acid, essential to the growth of plants, is not mentioned, not having been specially sought for, but is included in the items of "loss." In a formation productive of such rich vegetation as the Red Marl, we might infer beforehand the existence of this ingredient; and in reply to an inquiry on this point, Dr. Voelcker informs me that there is always in the Keuper marls an appreciable quantity of phosphoric acid, varying from 0·2 to 0·3 per cent. It would be an interesting point to determine whether in the case of the fossiliferous Liassic clays there is not a larger per-centage than in the comparatively barren strata of the Keuper. In the case of the Oolite limestones, Dr. Voelcker has long since shown that the most productive cereal soils are those

* "Principles of Geology," 10th edition, vol. i., p. 411. How much longer it is impossible to say, probably since the close of the Glacial Epoch.

† Extracted from Mr. Maw's paper on "Variegated Strata," Journ. Geol. Soc., vol. xxiv., p. 370.

which rest on the beds containing the greatest proportion of phosphate of lime, as, for instance, the Cornbrash.

Manner of Distribution of the Red Marl.—The Red Marl, like the Bunter Sandstone beneath, has been originally deposited over the Midland counties of England on an uniform plan of distribution, owing to which it attains its greatest vertical development towards the north-west of the country, and becomes gradually more attenuated as we trace it towards the south-east to the borders of the Lias in Warwickshire.

In Cheshire the thickness of the Keuper series has been much underestimated by previous writers. Mr. Ormerod, from considerations connected with the depths of the salt beds, places the thickness at over 700 feet,* but from the disconnected state of the sections, owing to the concealment of the strata by Drift deposits, and the uncertainty as regards the presence of faults, which there are no definite means of tracing, it is impossible to arrive at the actual thickness of the formation in the central plain of Cheshire. That the thickness is very great, however, appears probable at first sight from the large expanse of ground which the strata overspread; and fortunately for us, at least one section is open to view, which enables us to assign a minimum thickness to the beds; this section is shown along the banks of a brook, which crosses the strike of the beds three miles south of the village of Malpas, descending for a distance of two miles through strata of the Red Marl into those of the Lower Keuper Sandstone. Throughout this distance there is an average dip of 15° to the S.E., and in this portion of the series alone there is brought to view about 2,300 feet of strata. Some of these beds may possibly be repeated over again by concealed faults, but, on the other hand, it must be recollected that where the section ends to the eastward in the direction of the dip, the beds are a long way from the margin of the Lias. Taking all things into account, I think that 3,000 feet is the least thickness which would be found if these beds were penetrated below the Lias of Prees; and if we add 450 feet, the thickness of the Lower Keuper Sandstone, as ascertained by the measured sections of the Geological Survey, we have a total of 3,450 feet as the thickness of the Keuper division of the Trias in Cheshire.

On the other hand, if we cross over to the south-east into Warwickshire, we find this formation considerably reduced in thickness. Mr. H. H. Howell, of the Geological Survey, has determined the thickness between the margin of the Lias east of Coventry and Warwick and the western outcrop of the beds to be 600 feet, and if we add 150 feet for that of the Lower Keuper Sandstone, we have a total of 750 or 800 feet for the Keuper division in this part of the country. In the central parts of Staffordshire the upper limit of the Keuper marls is indicated by the presence of the Lias and Rhætic beds on the high grounds of Needwood Forest.† It is probable that the thickness of the Keuper division is not less than 1,500 or 2,000 feet, as its position is intermediate between that of Warwick and Central Cheshire. In Gloucestershire the thickness is variable, but the maximum may be assumed at 500 or 600 feet, and we shall probably not be in error in assigning a similar development to the beds in Nottinghamshire. It is extremely improbable that the Keuper series extends to a great distance under the eastern counties. The total absence of these beds under the Chalk at Harwich has been proved by a boring for water there, and the

* Journ. Geol. Soc., vol. iv., p. 288.

† First described by Mr. J. B. Jukes of the Geological Survey, in the Memoir "On the Geology of the South Staffordshire Coal-field," 2nd edit., p. 3.

probabilities are that somewhere under the tract corresponding to the north-western margin of the Cretaceous formation, the Triassic strata terminate against the old shelving shore of Palæozoic rocks.

Several years ago, when bringing the above facts and inferences before the Geological Society of London, I stated my conviction that the south-easterly attenuation of the Triassic strata was due to the tailing out of the original sediment consequent on the increasing distance from the original source of supply which lay in the direction of the Atlantic Ocean, and that there was reason for believing that the Liassic series undergoes a similar process of thinning away in the same direction.*

Rhætic or Penarth Beds.—The Triassic series terminates upwards with a remarkable series of beds, of no great vertical thickness in this country, but which in Lombardy (the ancient Rhætia) as well as in other parts of the continent, assume a high degree of stratigraphical and palæontological importance, in consequence of which the term "Rhætic beds" has been applied to them by Mr. Charles Moore.† To the same group the name "Penarth beds" has been applied by Mr. H. W. Bristow of the Geological Survey,‡ in consequence of their conspicuous appearance and the fine sections which they present in the bold headlands and cliffs at Penarth on the Bristol Channel. But to Dr. Thomas Wright, of Cheltenham,§ clearly belongs in order of priority the credit of pointing out the relations of these beds to those of the Lias, and of indentifying them with their Continental equivalents, &c. described under the names of the "Rossenger-Schichten" of Von Hauer and Oppel, and of "Die Schichten der *Avicula contorta* inner- und ausserhalb der Alpen" of Winklen. Following the precedent of this latter observer, Dr. Wright (1860) named this group "*the Avicula-contorta beds,*" and separated it from the true Lower Liassic series above, and which are characterized by the first appearance of *Ammonites planorbis, A. Bucklandi,* and *Ostrea Liassica.* Previously to this, however, it must be remembered that Sir Philip Egerton in 1841, from an examination of several species of placoid and ganoid fishes obtained from "the bone beds" of Aust Cliff and Axmouth, had come to the conclusion that the beds from which they were derived (those of the *Avicula contorta*) ought to be referred to the Triassic series rather than to the Lias ;‖ and the late General Portlock in naming this fossil *Avicula contorta* as found by him in the north of Ireland, in black shale overlying the red marls of the Keuper, and in turn superimposed by beds of calcareous grit, with Saurian and Fish remains, considers these beds as "a connecting link between the New Red Sandstone and the "Oolitic systems," and points out that the fish *Acrodus minimus* (Agassiz), *Gyrolepis Alberti* (Ag.), and *G. tenuistriatus* (Ag.) are truly Muschelkalk species.¶ These remains are also found in the Rhætic beds of Aust Cliff, &c.

As defined by Dr. Wright, the Rhætic beds may be considered to include all the black shales with their interstratified sandstones, lime-

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* "On the Thinning-out of the Secondary Strata," Journ. Geol. Soc., vol. xvi., p. 63 (1859).

† Journ. Geol. Soc., vol. xvii., p. 483.

‡ "On the Rhætic (or Penarth) Beds of Bristol and the South-west of England." By H. W. Bristow, F.R.S. (communicated by Sir R. I. Murchison), Brit. Assoc. Report, Bath, 1864. See also MM. Bristow and Dawkins on the same subject, *Geological Magazine,* 1864.

§ "On the Zone of *Avicula Contorta,* &c.," Journ. Geol. Soc., vol. xvi., p. 374.

‖ Proc. Geol. Soc., vol. iii., p. 409.

¶ "Geology of Londonderry," p. 107.

stones, together with "the bone beds" described by the late Mr. Strickland, which lie between the grey, green, and red marls of the Keuper and the lowest blue shales and limestones characterized by *Ostrea Liassica* and the Ammonites already mentioned. It also includes a band of argillaceous limestone with remains of fossil Insects described and traced at intervals over a large portion of Somersetshire and Gloucestershire by the Rev. P. B. Brodie,* and a peculiar stratum of cream-coloured compact limestone, known amongst geologists as "the White Lias." One of the beds of this White Lias is more popularly known as the Cotham marble or "landscape stone," the latter name having reference to the peculiar markings resembling a landscape with trees, &c., which the stone presents when fractured at right angles to the bedding. Mr. Bristow states that north of the neighbourhood of Bristol this limestone forms the upper limit of the Rhætic group, and is often found with an eroded surface. At Puriton and some other places the uppermost bed of the White Lias is perforated by boring molluscs, giving evidence of a break in the succession of the beds at this horizon immediately at the base of the true Liassic strata.

The Rhætic beds in some instances do not exceed 15 to 20 feet in vertical thickness, but in the neighbourhood of the Bristol Channel, where they are more fully developed, the thickness is much greater, amounting to about 50 feet near Penarth.

As yet these beds have not been traced further northward than the outlier of Copt Heath near Birmingham,† and at Abbots Bromley in Staffordshire, where the occurrence of the peculiar sandstone of this group has been noticed by Mr. Howell of the Geogological Survey. The special description of these beds, already so fully given by Wright, Moore, Bristow, Dawkins, and Etheridge, does not come within the scope of this Memoir; but I have thought it necessary to give the above brief outline of the character and affinities of this group of strata, which, both by its remarkable series of organisms, and from the fact of its occurrence in unbroken sequence above the Keuper Marls, seems properly to be referable to the Triassic formation, and redeems it from the reproach of barrenness.

CHAPTER X.

Physical Geology of the Trias.

There is abundant evidence that at the close of the Permian era there were physical disturbances of considerable intensity, accompanied and followed by the denudation of a vast amount of strata belonging to the Palæozoic formations. It was at this period that the elevation of the Penine chain along lines trending north and south occurred, resulting in the disseverance of the coal-fields of Lancashire, Cheshire, and North Staffordshire, from those of Yorkshire, Derbyshire, and Notts.‡ And

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* Proc. Geol. Soc., vol. iv., p. 14.

† By the Rev. P. B. Brodie, Vicar of Rowington.

‡ As I have endeavoured to show in my paper "On the relative Ages of the "Physical Features of the Carboniferous Rocks of Lancashire and Yorkshire," Journ. Geol. Soc., vol. xxiv. The name "Penine Chain," applied by Conybeare and Phillips in their "Geology of England and Wales" to the range of lofty moorlands which trend in a northerly direction from Derbyshire to the borders of Scotland, and by these authors adopted from the Roman name "*Alpes Penini*," is clearly of Celtic origin from "Pen," the head, also a hill or summit of elevation.

it may be affirmed that the intersection of these north and south lines of elevation of post-Permian date, with those of post-Carboniferous date crossing from west to east, or nearly at right angles thereto, has resulted in the production of nearly all those complicated foldings and fractures of the strata which characterize the Lower Carboniferous region of Derbyshire and Yorkshire.

Over a basin much more extended than the present limits of the Bunter formation, and hemmed in by the highest parts of North Wales, Salop, and the older Palæozoic barrier of Central England on the south, the lowest beds of the New Red Sandstone were spread by currents bringing sandy sediment from the north-west. The deepest parts of this basin were situated in Mid-Cheshire and East-Shropshire; and the sandy sediment was then spread out in greatest quantity towards the north-west, gradually tailing out towards the south and east of the basin; that is, in South Staffordshire, Warwickshire, and Leicestershire.

At the commencement of the second stage, that of the Pebble beds, certain physical changes ensued, probably of a slightly elevatory character, resulting in the formation of true shingle beaches along the Welsh and Salopian borders of the basin, and the marginal lands to the eastward, though only in a very minor degree. But as time went on these local gravels gave place to conglomerates of water-worn quartzites and other rocks, which seem to have been drifted from the northward; for along with these predominant and peculiar pebbles of quartz-rock we find fragments of Carboniferous Limestone, from tracts in the north of England at that time only partially submerged. These conglomerates are in fact an old "northern drift;" and I think, for reasons stated in another page,* we may confidently regard them as derived from the waste of the Old Red Conglomerates and other rocks of Scotland, or adjoining districts now submerged under the sea, or destroyed by denudation.

In Derbyshire, in the neighbourhood of Ashbourn, and along the southern flanks of the Weaver hills, the Conglomerate beds are found folding around the Carboniferous rocks, and filling the old bays in positions from 500 to 600 feet below the highest parts of these hills. In the valley of the Churnet the same beds occupy an old depression in the Yoredale series, hollowed out along the anticlinal axis of elevation, and if there had been a less amount of denudation along the western limits of the formation we might have found similar instances of these beds clinging to the old coast lines of subærial districts. As in the case of the earliest stage, the Conglomerate beds thinned away in the direction of the central barrier of older Palæozoic rocks now concealed under parts of Worcester, Warwick, and Leicester, and the Eastern Counties.

At the close of the Conglomerate period fine sandy sediment began to be distributed by currents from the north-west, over a gradually subsiding area; and, as in the case of the two lower subdivisions, the Upper Mottled Sandstone attained its greatest development in the direction from which it was derived, and tailed out towards the central barrier. With this third stage, the period of the Bunter Sandstone was terminated.

The close of the Bunter Sandstone period in England was accompanied by a general elevation into dry land of the whole of the Triassic area, in which condition it remained throughout the period of the Muschelkalk; this hypothesis seems sufficiently to account for the absence of that formation in this country.

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* Pages 59-61.

With the introduction of the Keuper period the British area was again submerged, and this submergence was accompanied by a certain amount of denudation of the Upper Mottled Sandstone, of which we have abundant evidence in Lancashire and Cheshire. The introductory stage of the Keuper series was the formation of a second shingle beach, very largely developed in Shropshire and Worcestershire, but also in a less marked degree all over the Central counties. These local breccias, which were formed in waters charged with calcareous matter, gradually gave place to alternations of fine sand and mud periodically laid dry over large tracts of country, as shown by the footprints of reptiles, and other subærial phenomena.

This brings us to the consideration of the interesting question whether the Triassic rocks were formed in the waters of an inland lake or of the open sea, and in the absence of fossil shells, which are the surest guides in such an inquiry, we are obliged to rely on less certain evidence.

With regard to the Bunter Sandstone, the evidence on either side is almost nothing;* but when we come to consider the phenomena connected with the lower beds of the Keuper, we have a certain weight of evidence which seems to lead only in one direction, namely, the lake origin of the formation.

This view is now very strongly held by some of our physical geologists, such as Professor Ramsay, Mr. Godwin-Austen, and the late Professor H. D. Rogers. These geologists hold that the very existence of salt-rock in these beds is a proof of their lake origin, as it is extremely improbable (perhaps we might say inconceivable), that such deposits could accumulate in the open sea.

The Dead Sea is perhaps one of the best illustrations in our day of an inland lake, such as that in which the lower beds of the Keuper, at least, were deposited. This sea has no outlet, while the River Jordan is constantly carrying into it salts of several kinds. Now, as the water is year by year being evaporated as fast as it is poured into the lake, it leaves these salts behind, which have resulted in super-saturation, and their consequent precipitation over the bed of the lake. In a similar manner we may suppose the beds of rock-salt of Cheshire and Worcestershire to have been formed in an inland lake at a period corresponding to the commencement of the stage of the Red Marl, as well as the irregular bands of gypsum which occur throughout the whole stage; and this saturation with saline matter will serve to account for the absence of mollusca in the red marls; another point of resemblance with the beds forming in the Dead Sea, in which there is scarce a trace of any living animal.

The Great Salt Lake of America, as suggested to me by Professor Ramsay, might be cited as another illustration of the formation of salt beds like those of the Keuper.

We have now to account for the desiccation of such large portions of the bed of this inland sea or lake, as shown by the foot-prints, sun-cracks, and impressions of rain-drops. If unconnected with the ocean, it is evidently impossible to refer them to tidal oscillations. Professor Ramsay has suggested an explanation which appears completely to meet the case. He supposes that the periods of desiccation represent the periodic returns of hot and dry summers, when the rivers were reduced to their smallest dimensions, and large tracts were laid dry by evaporation; on the return of autumnal rains the waters would again overflow

* Mr. Godwin-Austen, with many other geologists, inclines to the freshwater (or inland sea) origin of the Bunter. At the same time it is to be remembered that marine shells occur in the upper beds of this formation on the continent.

the bed of the lake, and new sediment would be deposited over the parched and cracked surface-stratum of the previous year. These changes can only be held as applicable to the period of the Lower Keuper Sandstone, with an occasional interval during that of the Red Marl, but this latter formation was probably deposited in deeper water, over a wider area, and over a deepening lake bottom.

It must not be forgotten, however, that Professor Rupert Jones has found marine foraminifera in the higher beds of the Red Marl at Chellaston; and we may suppose that towards the close of the period the waters of the ocean may have gained access into this inland sea in which the Red Marl was deposited, perhaps on more than one occasion; and that at the close of the Triassic period, owing to the great and general subsidence of this part of Western Europe, they established their dominion over the whole region occupied by the Trias, bringing in their train the multitudes of marine animals which peopled the waters of the ocean during the Rhætic and Liassic periods.

South-easterly Attenuation.—The thinning away of all the Triassic strata from the north-west towards the south-east of England is a fact connected with the physical geology of this country, which I think is now very generally recognized by geologists, and one which some years ago I endeavoured to demonstrate in the pages of the Journal of the Geological Society of London.* This view has been arrived at by taking a series of vertical sections of the strata along a line of country between the estuaries of the Mersey and of the Thames, founded on the measurements of the Geological Surveyors, and comparing them with each other. Some of these results have been already anticipated in these pages when tracing the marginal limits of the sub-divisions of the Bunter Sandstone; for we found that they all decreased in thickness towards East-Warwickshire, where they entirely disappear. The following summary of the comparative thickness and range of the sub-divisions may be taken as a very close approximation.

COMPARATIVE THICKNESS AND RANGE OF THE TRIASSIC SERIES ALONG A SOUTH-EASTERLY DIRECTION FROM THE ESTUARY OF THE MERSEY.

Name of Formation, &c.		Lancashire and W. Cheshire.	Staffordshire.	Leicestershire and Warwickshire.
		Feet.	Feet.	Feet.
Keuper Series	Red Marl - - -	3,000	800	700
	Lower Keuper Sandstone -	450	200	150
Bunter Series	Upper Mottled Sandstone -	500	50 to 200	Absent.
	Pebble Beds - - -	500 to 750	100 to 300	0 to 100
	Lower Mottled Sandstone -	200 to 500	0 to 100	Absent.

A plan of distribution so definite and uniform in its results cannot be attributed to local or momentary causes, but is evidently connected with the original distribution of the sediment of which the beds are formed, and the source from which it was derived. That source was the great continent which occupied the North Atlantic during this and other periods of geologic history, and the thinning out of the strata is evidently due to the increase in distance towards the south-east of England from the source of supply. To what extent the Keuper

* "On the South-easterly Attenuation of the Lower Secondary Rocks of England."—Journ. Geol. Soc., vol. xvi.

beds are prolonged towards the south-east beyond their known limits it is impossible to say; we may however suppose that they become still more attenuated, and ultimately terminate along the sides of the barrier of Older Palæozoic rocks which I believe to underlie the Cretaceous formations of the eastern counties.*

CHAPTER XI.

Distribution of the Coal-Measures beneath the Triassic and Permian Formations of Central England.

In order to arrive at clear views on this important economic question, it will be necessary in the first place to trace out the original margin of the Coal-measure area; then to determine the lines and districts of disturbance and denudation to which the Coal-measures have been subjected at the close of the Carboniferous period; after which we shall consider what districts have been upheaved and subjected to denuding agencies after the Permian period; and lastly the mode of distribution of the Triassic and Permian rocks.

Original Coal-measure Area.—The known Coal-areas of England seem to have been deposited to the north and south of a tract of Carboniferous land surface to which I have several times alluded under the term of "the Barrier." This tract of land appears to have extended from Wales, Shropshire, and Herefordshire towards the eastward along the southern margin of the South Staffordshire Coal-field, where its presence has been traced during the prosecution of mining operations by Sir Roderick Murchison,† Mr. Jukes,‡ and Professor Ramsay.§ The prolongation of this land surface may again be recognized in the Cambrian rocks of Charnwood Forest, and between this part of its range and that of South Staffordshire and Worcestershire there was probably a deep bay stretching in a southerly direction, which was filled in by the prolongation of the Leicestershire Coal-field; the north-western margin of this barrier cannot be traced farther by actual observation, but may not improbably be regarded as extending in the direction of the estuary of the Humber, and as having formed an extension of that "old land surface" of Scandinavia and the German Ocean, which Mr. Godwin-Austen maintains, on physical grounds, to have existed throughout the Middle and Upper Palæozoic periods.‖

The barrier, thus defined, separated the coal-tracts of the south of England and South Wales, from those of the Midland Counties and the north of England, which extended uninterruptedly at least as far north as the Southern Uplands of Scotland.

Confining our attention to the region north of the central barrier, it will be well to notice briefly the mode of distribution of the Coal-measures over this area, because it bears upon the productiveness of the Coal-fields themselves under the newer formations.

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* The boring for water at Harwich, which proved that the Cretaceous beds rest directly on Lower Carboniferous Slate with *Posidonia*, shows that the whole of the Triassic series is thus absent.

† This margin of Old Silurian Rocks was found on Lord Dartmouth's property by a sinking, the details of which are given in the "Silurian System," p. 476.

‡ Preface to the "Memoir on the S. Staffordshire Coal-field," 2nd edit.

§ During the sinking of Mr. Dawes' pit, strata were reached about the position where the thick coal ought to have been found which Professor Ramsay has identified as Upper Ludlow rock, with remains of *Pterygotus*.

‖ Quart. Journ. Geol. Soc., vol. xii. See map, page 46.

Now, if we take a series of comparative vertical sections at intervals along a line extending from North Lancashire into Warwickshire, we find that the sedimentary strata of the Carboniferous age undergo a very decided decrease in thickness when followed from the north-west to the south-east, and that the included seams of coal undergo a similar, though scarcely proportionate, diminution in vertical dimensions. Thus if we take four points of comparison along the line indicated we find the following remarkable results.

Sub-divisions.	N. Lancashire. Burnley District.	S. Lancashire. Manchester District.	N. Stafford-shire.	Leicestershire and Warwickshire.
	Feet.	Feet.	Feet.	Feet.
Coal-measures - -	8,460 *	7,630	6,000	3,000
Millstone Series - -	5,000	2,000	500	} 100 to 500
Yoredale Series - -	4,675	2,000	2,300	
Total - -	18,135	11,630	8,800	3,100 to 3,500

I shall not here enter into any theoretical considerations regarding the cause of this general attenuation of these beds, which, it will be observed, are more recent than the Mountain Limestone, having treated of that question elsewhere,† but it will be apparent from the above considerations that the Coal-measures were distributed in greatest force in the region of the north of England, and became much thinner in the direction of the central barrier of the Older Palæozoic rocks which, it is presumed, formed their southerly limit.

At the close of the Carboniferous period the Coal-measure tract above described was subjected to powerful movements along east and west lines throwing the beds into large folds; and, being followed by denudation on an extensive scale, resulted in the destruction of large tracts of coal-bearing rocks, and the elevation to the surface of the Lower Carboniferous strata. These movements produced the severance of the Yorkshire from the Durham Coal-field, and the determination of the northern limits of the coal-bearing strata of Lancashire along the line of the Pendle axis of elevation.‡

Another axis, or system of flexures, was originated along the southern margin of the Carboniferous Limestone region of Derbyshire, extending westward along the valley of the River Dane, north of Congleton Edge, and, as I infer, under the central plain of Cheshire to the southern end of the Flintshire Coal-field. If this inference is correct, Coal-measures will not be present under a band of country stretching across this plain from west to east by Middlewich and Tarporley.§ This axis I suppose to have formed a portion of the dividing ridge, or barrier, between the Permian basins of Lancashire, Cheshire, and the North of England on the one side, and of Shropshire, Staffordshire, and the Central counties on the other.

* The upper beds of the Coal-measures have been denuded away in the Burnley district. In order therefore to obtain the full thickness, as originally deposited, I have added to the Burnley series the thickness of the upper Coal-measures as determined near Manchester.

† "On the relative Distribution of the Carboniferous Sedimentary Strata, &c."—Journ. Geol. Soc., vol. xviii., p. 127; also "On the Thickness of the Carboniferous "Rocks of the Pendle Range, &c."—Brit. Assoc. Rep., 1867, and Quart. Journ. Geol. Soc., vol. xxiv., p. 319.

‡ "On the relative Ages of the Physical Features of Lancashire and Yorkshire."—Brit. Assoc. Rep., 1867, and Geol. Journ., vol. xxiv., p. 323.

§ I have stated the reasons for this inference in a former chapter. See Chap. iii., p. 28.

Permian Beds.—Over the Carboniferous area thus partially disintegrated at the close of the disturbances just related, the Lower Permian beds of Central England were deposited within a basin, only a little more extended than that of the Coal-measures, bounded on the south by the central barrier, on the north by hypothetical Carboniferous ridge of Mid-Cheshire, on the east by the Cambrian and Carboniferous rocks of Leicestershire, and on the west by older Palæozoic land surfaces of Shropshire and North Wales. The Lower Carboniferous beds, upraised along a band of country between the Leicestershire and Nottinghamshire Coal-fields, formed the margin of the basins which separated the Permian basin of the north-east of England from that of the Central counties.

At the close of the Permian period a new series of vertical movements took place principally along north and south lines, at least in the north of England. These disturbances, accompanied and followed by denudation, resulted in the disseverance of the Coal-fields of Lancashire and Cheshire from those of Yorkshire, Derbyshire, and Nottinghamshire. To the intersection of these two great systems of disturbance (those along east and west being at the close of the Carboniferous period, and those along north and south lines at the close of the Permian) may be mainly referred all those complicated flexures and fractures which characterize the rocks of the elevated and rugged tract of the Penine chain from Derbyshire northward into Yorkshire.

Concealed Coal-bearing Tracts, Cheshire, &c.—We are now in a fair position to determine under what districts the coal may be expected to lie. I will venture to give a description of the general position of the coal-seams around the Permian and Triassic areas of South Lancashire and North Cheshire. Commencing in the neighbourhood of Macclesfield, and proceeding along the district of the Poynton coal-field in Cheshire, the coal-seams all dip steadily in a westerly direction under the Triassic and Permian rocks; and crossing into South Lancashire at Dukinfield and Ashton-under-Lyne, we find that they dip in the same direction also, under the Permian and Triassic rocks; and if we continue that examination westward along the southern margin of the Lancashire Coal-field we find almost continuously, except where interrupted for a short distance by faults, a general tendency of the coal-seams to dip in the direction of the newer formations towards the south. Then, if we cross over to the Flintshire Coal-field, we find along the estuary of the Dee a similar tendency to dip towards the north-east in the direction of the newer formations. But when we come down to the neighbourhood of Hope, to the south-west of Chester, we there find the Millstone Grit and Lower Carboniferous beds brought up, and overlapped directly by the New Red Sandstone. This uprising of the Lower Carboniferous rocks to the south of the Flintshire Coal-field indicates the westerly appearance from beneath the New Red Sandstone of the barrier of Lower Carboniferous rocks which, as I suppose, stretches underneath the Cheshire plain. Therefore I think we may assume that north of that barrier, and extending to the margins of the Flintshire, the South Lancashire, and the Cheshire Coal-fields, there is a large tract in which the coal most certainly exists, including the peninsula of Wirral.

Then if we come to examine the Denbighshire Coal-field, a coal-field which there can be no question is one of very great economic importance, we find the coal-seams dipping steadily in an easterly direction, overlaid by a thick series of upper unproductive Coal-measures, and those overlaid by a thick series of Permian strata, but everywhere there is a steady easterly dip; and on the opposite side of the plain along the western margin of the North Staffordshire Coal-field we find also a

tendency in the coal-seams to dip towards the west and south under the Permian and the Triassic rocks. Therefore I think that there is very little doubt that coal exists between the western outcrop of the Denbighshire Coal-field and the eastern outcrop of the North Staffordshire Coal-field; south of that barrier of Lower Carboniferous rocks, the position of which I have already indicated. The southern margin of this concealed coal-field it is somewhat hazardous to conjecture, because there is very strong evidence that ridges of the older Silurian rocks stretch in a north-easterly direction under the Triassic and Permian strata; and therefore, until we know how far these extend, we cannot be certain of the actual limits of the coal-field. For example, taking the western side of the Coalbrook Dale Coal-field, it is quite certain that the New Red Sandstone is there brought in by a fault, still I do not think that that fault is of so much importance as to throw in any great amount of the Coal-measures, and it is almost certain that underneath the New Red Sandstone for a considerable distance we should find Silurian rocks only.*

District between the Coalbrook Dale and South Staffordshire Coal-fields.—As regards the tract of Triassic and Permian rocks to the east of Coalbrook Dale much caution ought to be observed in speculating on the existence and depth of the Coal-measures, on account of the possible uprising of Silurian rocks, or ridges. I may just say, however, in a few words, that the uppermost seams of coal appear to die out, as I have been informed, along the line of an inclined plane, sloping towards the eastward; and how far downwards into the coal-seams that plane extends is a question which can only be solved by actual experiment. But I myself can scarcely doubt that the lower and middle coal-seams of this coal-field extend, I do not know whether to say uninterruptedly or not, but for a very considerable distance under the Permian and Triassic rocks to the east of the Coalbrook Dale Coal-field, in all probability joining with the same beds on the west side of the Triassic and Permian area at Wolverhampton and Cannock Chase.

It would be, I think, in the highest degree hazardous to expect any valuable coal-seams under a very large tract of Permian and Triassic rocks at Enville and the east of Bridgnorth, because, as we have already seen, we are there approaching the original marginal limits of the Coal-formation, and in that direction the main beds of coal certainly die out. But north of some indefinite line, which perhaps may be drawn from the valley of the Severn at Ironbridge on the west to Stourbridge on the south-east, in all probability valuable and productive seams of coal would be found; but I would not recommend any trials to the south of that line.

District between the South Staffordshire and Warwickshire Coal-fields.—If we now come to the district east of the South Staffordshire Coal-field, we have there, when looking for a continuation of productive seams of coal, to guard against the uprising of the Silurian rocks along the original margin. But as the seams of coal have been shown by my colleague, Mr. Howell, to range continuously along the Warwickshire coal-field as far south, at least very nearly, as Coventry,† there can be no question that north of a line which I should be disposed to draw from Coventry to Walsall we have a region of productive Coal-measures.

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* This is corroborated by the results of a boring made on the Hadley Park estate, north of Wellington, in which hard trap rock was proved to underlie the New Red Sandstone without the intervention of any Coal-measures, the trap being referable in all probability to the Silurian series.

† To the north of the river Sow, near the village of Wyken.—"The Geology of "the Warwickshire Coal-field," p. 22.

Between the northern limits of the Warwickshire Coal-field and the Leicestershire Coal-field, ranging as far as Measham and Ashby-de-la-Zouch, westward of a line joining these towns and Polesworth, I think there can be no doubt that we have a region of productive Coal-measures. This productive area will probably be found to stretch to the margin of the North and South Staffordshire coal-fields.

District between the North Staffordshire, Nottinghamshire, and Leicestershire Coal-fields.—In considering the tract to the north of the Leicestershire Coal-field, and in endeavouring to trace the northern limits of the productive area, we have to recollect the uprising and exposure by denudation of the Lower Carboniferous rocks before the Triassic period; for it is quite certain that the Upper Carboniferous beds with coal were subjected to a large amount of denudation at the close of both the Carboniferous and Permian periods, over this tract. But if we cross over to the Cheadle coal-field, and observe the direction of the dip of the coal-seams which lie nearly at the bottom of the series, we find that there is in this district, and that of the Potteries, a general south-westerly dip; and therefore we may infer that along a line drawn through Cheadle to Ashby-de-la-Zouch in Leicestershire, we should have the northern boundary of a productive area extending to the borders of the South Staffordshire and Warwickshire coal-fields.

On the other hand, we should in all probability find an unproductive area north of the line just indicated, and extending to the southern outcrop of the Nottinghamshire Coal-field, which may be prolonged in a south-easterly direction from the point of contact with the New Red Sandstone near Sandiacre. South of this prolongation no coal may be expected under the tract extending to the borders of the Leicestershire Coal-field and Charnwood Forest.

Easterly Limit of the Yorkshire and Derbyshire Coal-fields beneath the Secondary Formations.—I now come to deal with a matter of considerable economic, as well as theoretical, interest, namely, the question, whether this great coal-field which extends through portions of three counties may be regarded as a true basin rising to the eastward and terminating beneath the Secondary formations; or on the other hand extending to an unknown distance till it terminates against the flanks of that barrier of ancient rocks which we believe to have formed the original margin to the eastward and southward of the Carboniferous strata in this part of England. At one time I held the latter opinion, and I considered it not improbable that the Yorkshire and Durham Coal-fields might be connected underneath the Mesozoic rocks, owing to the general inclination to the eastward of the Lower Carboniferous beds along the west of the boundary of the Magnesian Limestone. This view, however, is strongly opposed by Sir Roderick Murchison in his essay on "The parts of England and Wales in which coal may, and "may not, be looked for beyond the known coal-fields,"* and, although I once leaned to it myself,† on reconsidering the matter, and with a fuller knowledge of the subject than I possessed some years ago, I am prepared to take an opposite view; and in accordance with the evidence I gave before the Royal Coal-Commission in 1868, I now believe the probability is in favour of the view that both the Yorkshire and Durham coal-fields are true self-contained basins.

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* Communicated to the Geological Section of the British Association at Nottingham, 1866.

† The line of possible connexion of the two coal-fields is shown in the map which accompanies my work on the "Coal-fields of Great Britain," 2nd edit., 1861.

This view receives additional confirmation both from analogy with the other Coal-fields, and from the fact, as ascertained by my colleague, Mr. H. H. Howell, that the Coal-measures along the coast of the Northumberland Coal-field have an inland, or westerly dip. We have here clear evidence that the great northern Coal-field is a true basin, and if so, the probabilities are that the strata of the Yorkshire Coal-field also, in like manner, assume the form of a basin, and rise to the eastward beneath the Mesozoic formations.

This view is also strongly held by Professor A. C. Ramsay, who has pointed to the general tendency of the British Coal-fields to arrange themselves in the basin-shaped form as illustrated by the examples of the coal-fields of South Wales, Forest of Dean, Bristol, and some of those of the northern counties, when taken in groups. The evidence of the basin-like form of the Durham Coal-field is also very strong. Mr. H. H. Howell informs me that along the coast of Northumberland, in the neighbourhood of North Seaton, the Coal-measures tend to rise seaward, showing that the northern part of the Coal-field, at least, assumes the form of a basin. Sir Roderick Murchison had previously stated the same fact; but as the views of the eminent geologists who have investigated this question will be more fully exhibited on the publication of the Report of the Royal Coal-Commission, I refrain from further discussion of them here.

The evidence, however, which seems to me to point most conclusively in the direction of the above view, is the powerful character of that great series of elevatory movements which determined the northern outcrop of the Lancashire and Yorkshire Coal-fields along the Pendle axis of elevation. We trace this great upheave, not only along the northern limits of the Burnley basin, but as Professors Phillips and Sedgwick have shown, we find it continued all across the country to the eastward by Skipton, Otley, and to the south of Harrogate. There is every reason to suppose this axis is continuous to an indefinite distance to the eastward, effectually terminating the coal-bearing rocks along a line in the direction of the estuary of the Humber. My colleague Mr. A. H. Green, of the Geological Survey, has also lately pointed out to me as the result of his examination of this coal-field, that the axis stretches *not* along a north and south line, but along a line drawn through Bradford in a south-south-easterly direction in the direction of Worksop, thus giving the coal-field an oval form, of which a slight bend to the southward would convert the northern into an eastern outcrop.

Time will show, as mining operations make progress eastward under the Permian and Triassic rocks, what amount of truth there may be in these theoretical views; but in the meanwhile, with the evidence before us, and the analogy of other districts, I think we are justified in supposing that the Yorkshire and Derbyshire coal-field ultimately rises and crops out to the eastward under the Mesozoic formations ere the original margin of the Coal-measures has been reached; and in this manner it is represented on the map of the coal-bearing tracts of England which I prepared at the request of the Coal-Commission.*

The total absence of productive coal-measures under the Eastern counties of England, as well as portions of Gloucester and Worcester is a view which is maintained by Sir R. I. Murchison in the essay already quoted, and which was read before the British Association at Notting-

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* This map has been engraved, and will accompany the Minutes of Evidence given before the Royal Coal-Commission, Section D.

ham. On a subject of such interest I shall venture to quote one or two passages, from which it will be seen, that there is a close accordance between the views I have expressed and those enunciated by the Director General. After treating of the district of Somersetshire and Gloucestershire, the author of the essay proceeds, "Who, for example, "would speculate on the chance of finding coal to the north of the "poor little coal-tract of Newent in Gloucestershire, when it is known "that on the north the Silurian and older rocks rise to the surface, "their flanks being covered at once by Permian, or New Red Sand-"stone? Equally absurd would it be to look for coal in those parts "of the Severn valley of Worcester which lie to the east of the Mal-"vern Hills, where the New Red Sandstone also lies directly upon the "crystalline and other rocks of that range.

"The Malvern Hills on the south-west, and Charnwood Forest on the "north-east, each composed of Cambrian rocks older than the Silurian, "form salient promontories which seem to me to be indicative of the "former southern coast line of those productive coal-fields of the "Central counties which have been raised up through the Permian and "New Red Sandstone formations. I would not affirm that the "southernmost of these fields, those of Leicestershire and Warwick-"shire, have no southern extension, though they give strong signs of "deterioration in that direction. I know, however, that to the south "of the South Staffordshire coal-field all the productive Coal-measures "have been found by actual trials to thin out; old rocks of the Silurian "age being reached beneath. I presume, therefore, that no further "efforts will be made in the more southern counties in that "meridian."*

CHAPTER XII.

The Bunter Sandstone as a Source of Water Supply.

The Bunter Sandstone is by far the most important water-bearing formation in England, with the exception perhaps of the Chalk and Lower Greensand, which combined occupy a much larger area, but on the other hand, from their geographical position, receive a much smaller amount of rainfall and yield harder water, owing to the presence in greater proportions of carbonate of lime. The water-bearing capabilities of each formation are due to similar lithological structures of the rocks themselves, and are independent of chemical constitution. They are due in each case to the permeability, the homogeneous texture, and composition of the strata in the first instance, and to their occupying large unbroken areas, and attaining, in many places, a considerable amount of vertical thickness. If the Bunter Sandstone, like the Coal-measures, or the Lower Permian beds of central England, was composed of a varying series of impervious marls, clays, and shales, alternating with the sandstones, its usefulness as a water-bearing rock would be lessened as regards both the quantity and quality of the water which might be drawn from it.

Many of our large towns are now partially, or entirely, supplied with water pumped from deep wells in the Bunter Sandstone; and several from copious springs gushing forth from this rock at its junction with some underlying impervious stratum belonging to the Palæozoic series.

* "On the Parts of England and Wales in which Coal may or may not be looked "for."—Trans. Brit. Assoc., 1866.

Of these latter, the Wall-grange springs, near Leek, in Staffordshire, which rise from the Conglomerate beds and produce a very large quantity of water, estimated by Mr. Elliot, the Engineer to the Potteries Waterworks, at 3,000,000 gallons daily, is one of the most remarkable examples. The water from these springs is pumped into Ladderedge reservoir, and is distributed from thence into the town of Newcastle-under-Lyme and the Potteries.* From two somewhat discordant analyses it appears that the quantity of solid matter varies from 8·70 to 12·26 grains per gallon.

Of the towns which partially, or altogether, are supplied from wells, a large number may be enumerated. Thus, commencing on the north-west of England, there are Liverpool, Birkenhead, Southport, Ormskirk, St. Helens, Manchester and Salford, Crewe, Birmingham, Wolverhampton, Stourbridge, Cheadle, and Nottingham, besides several smaller towns and villages.

The quantity of water which is capable of being pumped from wells properly situated is certainly surprising, and indicates the high permeability of the rock over large areas. The most remarkable instance is that of the Green Lane Well, situated a short distance to the east of Liverpool. The details of the operations at this well were kindly furnished some time since to the author by Mr. Duncan, the resident Engineer to the Corporation. These details have special interest as illustrating the relations between the quantity of water in the rock and the depth from the surface.

The well was sunk in 1845–46, the surface being 144 feet above the sea-level, and the depth of the well 185 feet, or 41 feet below the sea-level. At first the yield was 1,250,000 gallons per day. A bore-hole, 6 inches in diameter, was then driven to a depth of 60 feet from the bottom of the well, when the yield increased to 2,317,000 gallons. In June 1853, the supply had slightly fallen off, being 2,303,000 gallons, upon which the boring was still further carried down 38½ feet, when the yield increased to 2,689,000 gallons. In June 1856, the bore-hole was widened and carried down 101 feet further, when the yield amounted to its present supply of 3,321,000 gallons per day.

From these boring operations we arrive at the following results:— In the first boring of 60 feet the increase was at the rate of 17,783 gallons per foot; in the second of 38½ feet, the increase was only at the rate of 9,789 gallons per foot, and in the third, only 6,277 gallons per foot. It is easy to perceive that any further increase would be at a rapidly diminishing ratio with the depth until a zero point had been attained.†

At Liverpool the quantity of water pumped from all the wells of the borough, both public and private, may be estimated at 5,000,000 of gallons, drawn from an area of about 20 square miles. Several wells situated within a quarter of a mile, and even a greater distance from the River Mersey, have been abandoned owing to the infiltation of salt water from the river itself. On the opposite side of the estuary of the Mersey there are several deep wells belonging to the Tranmere Local Board of Health, the Birkenhead Commissioners, and the Wirral Water Company, yielding together about 4,000,000 gallons, and in this district it is found that the subterranean waters of the Wirral Peninsula have

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* Wardle's "Geology of Leek," pp. 265, 266.

† The large quantity of water yielded by the Green Lane Well at Liverpool is probably due to the existence of a large fault which is considered to pass in a north-westerly direction by the well, and which acts as a duct for conveying the subterranean waters from a long distance on either side.

established a balance of pressure with those of the sea, so that when at first penetrated, the level of the water in the rock has been found to correspond nearly with that of mean tide. Pumping operations tend, of course, to lower this level; and as in the case of Liverpool, when these are carried on to such an extent as to disturb the equilibrium, the sea water finds ingress by percolation through the rock.

From observations made amongst the wells of Manchester and Salford in 1863 I ascertained that there are from 60 to 70 deep wells driven down into the New Red Sandstone and Lower Permian Sandstone in connexion with factories, breweries, bleaching and dying works, and yielding probably 6,000,000 gallons of water per day.* This large quantity of clear water, admirably adapted for commercial and manufacturing purposes, is drawn from an area which cannot be estimated at more than seven square miles, a great part of which is covered by buildings and paved streets, as well as being overspread by an almost impervious stratum of Boulder clay. The only way I can account for this supply from so restricted an area is by supposing that the waters of the rivers Irwell, Irk, and Medlock, which in their course traverse the New Red Sandstone along the suburbs of Manchester and Salford, find their way by percolation into the sandstone rock, from which they are afterwards drawn by pumping. If this be so, it shows what a wonderfully effective filter the sandstone is, for the waters of these rivers are so charged with impurities from various sources that the rivers themselves can be regarded as little better than filthy sewers.

In Birmingham, out of 7,000,000 gallons per day supplied to the borough by the Waterworks Company, 2,000,000 were derived from wells in the New Red Sandstone in 1865. In that year an Act was passed authorizing the sinking of several new wells, whereby the quantity will be largely increased; but it is probably unnecessary to adduce further illustrations, and I now proceed to discuss the causes of the excellence of the New Red Sandstone as a source of supply.

Porosity.—It was the opinion of the late Mr. R. Stephenson, the eminent Engineer, that the New Red Sandstone might be looked upon as almost equally permeable in every direction, and that the whole mass might be regarded as a reservoir up to a certain level; from which, whenever wells are sunk, water will always be obtained more or less abundantly.† Without accepting this opinion so fully as here expressed, it may, I think, be very fairly maintained that Mr. Stephenson's statement is borne out by experience, and that the occurrence of the water is not solely due to the occurrence of fissures or joints traversing the rock, but to its permeability in all directions. This of course varies in different districts. In the neighbourhood of Liverpool, to which Mr. Stephenson's observations chiefly extended, the rock (at least the Pebble beds) is less porous than in the neighbourhood of Whitmore, Nottingham, and Birmingham, and other parts of the Midland counties, where it becomes either an unconsolidated conglomerate, or a soft crumbly sandstone. Yet wells sunk even in the hard building stone of the Pebble beds either in Cheshire or Lancashire always yield water at a certain and variable depth. In the case of the Green Lane Well, however, we have seen that beyond a certain depth the water tends to decrease, a fact borne out by other cases.‡ Now, when water

* "On the New Red Sandstone and Permian Formations as Sources of Water-supply for Towns," Mem. Lit. and Phil. Soc., Manchester, vol. ii., 3rd series, p. 271.

† Report on the supply of water to Liverpool, 1850.

‡ Such as that of the St. Helens public well, situated on Eccleston Hill. At this well an attempt was made in 1868 to increase the supply by boring deeper into the sandstone, but without any good result.

percolates downwards in the rock, we may suppose there are two forces of an antagonistic character brought into play; there is the force of friction, increasing with the depth, and tending to hinder the downward progress of the water, while there is the hydrostatic pressure tending to force the water downwards; and we may suppose that when equilibrium has been established between these two forces the further percolation will cease.

The proportion of rain which finds its way into the rock in some parts of the country must be very large. When the rock (as is generally the case in Lancashire, Cheshire, and Shropshire) is partly overspread by a coating of dense boulder clay, almost impervious to water, the quantity probably does not exceed one-third of the rainfall over a considerable area; but in some parts of the Midland counties, where the rock is very open, and the covering of drift scanty, or altogether absent, the percolation amounts to a much larger proportion, probably one-half or two-thirds, as all the rain which is not evaporated passes downwards. This is evident in many instances from the total absence of local brooks and ditches in such districts, as in the neighbourhood of Cannock Chase, Kidderminster, and Stourport, and the dry gravelly lands of Sherwood Forest north of Nottingham. Springs, often very copious, burst forth, occasionally in positions favourable for the natural drainage of the rock, but there is often little or no surface drainage in such localities.

Homogeneous Structure.—The Bunter Sandstone, in its three divisions, may be regarded, in respect to water-supply, as a nearly homogeneous mass equally available throughout. The Upper and Lower Mottled Sandstones are, it is true, of a softer and more permeable texture than the Pebble beds in Lancashire, yet it is from the latter sub-division that most of the water in this county is actually pumped; while in the Central counties the Pebble beds pass into a conglomerate almost as open and unconsolidated as the sandstone of the upper and lower divisions.

It is owing to this homogeneous structure, and the almost entire absence of beds of impervious clay or marl, that the formation is capable of affording such large supplies of water; for the rain which falls on its surface, and penetrates into the rock, is free to pass in any direction towards a well when sunk in a central position. If we regard the rock as a mass completely saturated with water through a certain vertical depth, which water is in a state of equilibrium (or stagnation), when a well is sunk, and the water pumped up, the state of equilibrium is destroyed, and the water in the rock is forced in from all sides. The percolation is doubtless much facilitated by joints, fissures, and faults; and in cases where one side of a fault is composed of impervious strata, such as the Keuper marls, Coal-measures, &c., the quantity of water pent up against the face of the fault may often be very large, and the position may be very favourable for a well.

An instance of the effect of faults in the rock itself, in increasing the supply, is afforded in the case of the well at Flaybrick Hill, near Birkenhead. From the bottom of this well a tunnel was driven by the direction of Mr. Bateman, C.E., at a depth of about 160 feet from the surface, to cut a fault about 50 yards distant, and upon this having been effected the water flowed in with such impetuosity that the supply, which had been 400,000 gallons per day, was immediately doubled.

Quality of the Water.—We now come to consider the last and not least important question as regards water-supply, namely, the quality of the water as ascertained by experience. That the water

from the New Red Sandstone is clear, wholesome, and pleasant to drink; that it is also well adapted for the purposes of bleaching, dyeing, and brewing is proved by the large extent to which it is applied for these purposes; at the same time it must be admitted that its qualities as regards "hardness," in other words the proportions of carbonates of lime and magnesia it contains, are subject to considerable variation, depending on the locality and composition of the rock. As a general rule I think it may be stated that the water from the New Red Sandstone occupies a position intermediate between the "hard" water of the Chalk on the one hand, and the "soft" water supplied to some of our large towns from the river drainage of mountainous tracts of Palæozoic formations, of which the water supplied from Loch Katrine to Glasgow is perhaps the purest example, containing only 2·35 grains of solid matter to the gallon.

As an instance of very pure water from the New Red Sandstone, I know of none more remarkable than that from the well at Whitmore Station, sunk at the author's recommendation, for the supply of the town and works of Crewe in Cheshire. The supply here is very plentiful; and from the analysis of Dr. Zeidler it appears that there are only 6·10 grains of solid matter per gallon. Nearly equally pure is the water from the well of the London and North-western Railway Company at Parkside near Warrington, which, from the analysis of Mr. Dougall Campbell, F.C.S., is found to contain only 11·12 grains per gallon, distributed as under:—

Analysis of Water from the Well at Parkside.

Silica	0·80
Oxide of iron	0·24
Carbonate of lime	1·07
Sulphate of lime	1·63
Sulphate of magnesia	1·46
Carbonate of magnesia	0·70
Chloride of magnesium	0·71
Chloride of sodium	1·76
Potassium	0·11
Volatilized matter	2·64
	11·12

Degrees of hardness before boiling, 5·8; degrees after boiling, 4·1, according to Dr. Clark's standard. Of this water it was stated to the author by Mr. Ramsbottom, superintendant of the locomotive department of the London and North-western Railway, that there was none superior to it for engine-boilers to be found over the whole of the Company's railway system.

At Manchester, Dr. R. Angus Smith, F.R.S., has found that the water drawn from the deep wells of the Permian and Bunter Sandstone yields on an average eight grain of sulphate of lime and six grains of carbonate, besides other ingredients. One of the samples analyzed by Dr. Smith in 1865, from the south side of the city, I here reproduce in full.

Analysis of Well Water from the South Side of Manchester.

Chloride of sodium	4·88
Sulphate of soda	7·33
Carbonate of soda	7·35
Carbonate of lime	9·77
Carbonate of magnesia	5·29
	34·65

There were also traces of phosphoric acid, potash, and lithia; this last observed by the spectroscope. I attribute the large quantity of salts in this water to the fact of the saturation of the ground from chemical and other works around Manchester.

The amount of solid matter in water from four of the public wells in Liverpool varies from 13·6 grains in the case of the Green Lane Well to 24·8 grains in the case of the Soho Well, as ascertained by Mr. Richard Phillips; and at Birmingham the average proportion is 12 to 13 grains, as determined by Dr. Hill, F.C.S., analyst to the borough, and at Nottingham nearly the same.

With these small proportions of saline ingredients, which, while they tend to harden the water, are probably not without benefit in the animal economy, the water-supply from the New Red Sandstone possesses this incalculable advantage over that from rivers and surface drainage, that it is free from organic admixture, and cannot be impregnated with those deadly spores or seeds of disease which find their way into surface waters, and are so fatal in seasons of epidemic visitations.

Durham.—Large quantities of water are pumped from the Lower Permian Sandstone beneath the Magnesian Limestone of this county, and are used for the supply of the towns of Sunderland, South Shields, Jarrow, and several villages. This quantity, calculated by Messrs. Daglish and Foster* to reach five millions of gallons per day, is pumped from an area of 50 square miles overlying the Coal-measures. The water level has not been lowered in the rock by these operations. Along the coast it is that of mean tide, and inland rises to a level of 180 feet. In the Coal-measures below there is little water, and that little is saline.

Appendix (A.)

List of the (named) Fossils in the Warwick Museum, from the Keuper and Permian Sandstones, by the Rev. P. B. Brodie, M.A., F.G.S. Revised by Mr. Etheridge, F.G.S., Palæontologist to the Survey.

UPPER KEUPER.

Name.	*Locality.*
Ichthyodorulite, Leptodus (?) - - - - -	Shrewley Common.
Acrodus - - - - - - -	Ibid and Pendock.
Shagreen of Cestraciont.	—

LOWER KEUPER.

Labyrinthodon leptognathus (*Owen*).	Sternum - - -	-	Warwick.
„ „	- Dorsal vertebræ -	-	Leamington.
„ „	- Left ramus of lower jaw -		Cubbington.
„ „	- Part of lower jaw -		Warwick.
„ „	- Upper jaw and palate -		„
„ (Salamandroides)	- Part of jaw -	-	Leamington.
„ pachygnathus (*Owen*)	Ala of pterygoid bone (?)		Warwick.

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* Geological Magazine, vol. ii., p. 355.

Name.		*Locality.*
Labyrinthodon pachygnathus (*Owen*)	Head of humerus	Warwick.
„ „	Anterior frontal bone	„
„ „	Anguinal bone	„
„ „	Right superior maxillary	Cubbington.
„ „	Right osilium and head of femur.	Leamington.
„ „	Right ramus of lower jaw (2).	Cubbington.
„ „	Cranial bones	„
„ „	Bone (lower jaw)	„
„ ventricosus (*Owen*).	Serial tooth	„
„ „	Tusk of	Warwick.
„ conicus (?) (*Owen*).	Tooth	„
„ sp. inc.	Pelvic bone	„
„ „	Cranial bone	„
„ „	Tooth	„
„ „	Tibia	Leek Wootton.
„ „	Portion of upper jaw	Warwick.
„ „	Fragment of vertebræ	„
„ „	Superior maxillary bone	„
„ „	Toe bone	„
„ „	Cranial bone	„
„ „	Dorsal vertebræ	„
„ „	Dorsal vertebræ	„
„ „	Humerus	„
„ „	Coracoid	„
„ „	Cranial bone	„
„ „	Mastoid bone	„
„ „	Hinder part of right ramus.	„
„ „	Lower jaw (2)	
„ (Anisopos) scutulatus (*Owen*).	Dorsal scales	Leamington.
„ „	Vertebræ, portions of ribs, a humerus, a femur, tibia, dermal scutes, &c.	„
Cladydon Lloydi (*Owen*).	Teeth	Warwick.
Hyperodapedon (*Huxley*).*	Jaws, teeth, &c. &c.	Cotton End, near Warwick.

Many other bones and fragments not named. Slabs of footprints, viz., Labyrinthodon, (Cheirotherium) and Rhynchosaurus (?) Warwickshire, Staffordshire, and Cheshire.

PERMIAN.

Dasyceps Bucklandi (*Huxley*).	Cranium (two parts).	Kenilworth.
„ „ (?)	Part of jaw with teeth.	Coventry.
„ „ (?)	„ „	„

In my collection I have three fine and entire Ichthyodorulites of a Cestracionț, also Shagreen on skin of the same, the cutting teeth of a shark, also the palatal teeth, and group in jaw, very rare. A ganoid scale (*Palœoniscus superstes*), large mailed fish not in any collection; footprints of *Labyrinthodon*, *Rhynchosaurus*; Fucoids, a cast which I believe to be a bivalve shell. Plants (various), fruits of plants (?) *Estheria minuta*. All the above from Rowington and Shrewley.

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* On Hyperodapedon; see Prof. Huxley's paper in the Quart. Journ. Geol. Soc. vol. xxv., p. 138.

Appendix (B.)

Building Stone.

The sandstones of the Lower Keuper series are the most economically valuable of all which the Trias produces. In the central counties it is from them exclusively that the only good building-stone can be procured, the remaining beds being either too soft, or coarse, or pebbly to be used in the construction of edifices. In the western counties and Lancashire, though the other subdivisions in some measure enter into competition with them, the Lower Keuper Sandstone alone yields the white freestones which, in the choice of a building material for elaborate Gothic or Grecian architecture, must ever be preferred to coloured stone. In a land of comparatively cloudy skies, and a dull atmosphere, we need a lightly tinted stone to give lightness of effect to massive architecture; and that this preference has been kept in view from the earliest periods to the present day is exemplified in the great majority of our noblest buildings, from the days of our ruined Abbeys, and the venerable pile of Westminster, down to those of the new Houses of Parliament and St. George's Hall.

Quarries in the Lower Keuper Sandstone are very numerons, but the following list contains the best of those worked throughout the districts we have traversed.

Nearest large Town.	Locality.	Remarks.
Birkenhead	New Brighton, Wallasey	Yellow; middling.
„	Bidston, Stourton Hill	Light yellow and white; good.
Chester	Helsley, Delamere	Red; good stone.
„	Manley	White; good.
„	Peckforton Hills	Red; very hard.
Malpas	Overton Scar, Edgehill	White.
Market Drayton	Betton, Muxton	White and light red.
Shrewsbury	Grimshill	White; very good.
„	Weston	White.
„	Grug Hill, Baschurch	White; rather soft.
Wolverhampton	Railway near Albrighton	Brown and yellow.
„	Oreton Hill	White.
Birmingham	Wooley Castle	White.
Rugeley	Colton Mill	White.
„	Colwich	White.
„	Tixal and Weston	Light brown.
Cheadle	Fulford, Blythe Marsh	Light brown.
„	Woodhead	Light brown.
„	Crumpwood, Alton	White.
„	Hollington	White; very good.
Ashbourn	Stanton	White and light yellow.
Derby	Bowbridge Fields, near Kirk Langley.	White.
„	Weston Cliff, Donnington Park.	White and light brown.
Worcester	Ombersley	White and light red.

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